The Integrated Assessment of
Energy Options and Health Benefit

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1. Introduction

1.1 Objectives

This study is one of the components of ***The Integrated Study of Energy Option and Health Benefit in Shanghai***. The purpose of this study is to evaluate the reduction of local air pollutant emission and CO_2 emission under the assumed energy and environmental policies, and improvement of the pollutant exposure level. In order to achieve this objective following tasks have been done within this challenge project:

(1) Current status of energy consumption and its emissions in Shanghai. The consumption and its sectors should cover all the energy demand sectors and energy transformation sectors;

(2) Energy demand and its emission for year 2000 to 2020, under BAU and different energy-environment policy scenarios;

(3) Pollutant exposure level under current energy and environmental policies.

1.2 Sub-tasks

To answer the above questions, following subtasks had been carried out:

(1) Current status of energy supply and consumption in Shanghai;

(2) Secondary energy transformation;

(3) Total energy consumption and energy carriers consumed by the final sectors;

(4) Current status of air pollutant and CO_2 emission;

(5) Economic growth, energy demand, and emissions from year 2000 to 2020 in Shanghai;

(6) Energy system response in terms of energy consumption, local air pollutant and CO_2 emission reductions under future energy-environment policy scenarios;

(7) Pollutant exposure level under the energy-environment policies.

1.3 Project Implementation

This study is phased into three stages:

Phase 1: baseline data collection, including energy supply and consumption amount, amount and type of energy consumed by various sectors, relations between balanced energy use and emission.

Phase 2: energy supply and emission prediction. Based on the predicted economic growth rate, forecast potential energy demand and pollutant emission for year 2000 to 2020.

Phase 3: analysis under different scenarios and study on pollutant exposure level.

1.4 Baseline Data Collection

In order to understand the status quo of energy consumption and its emission, following data is collected as base information:

(1) Economic development and industrial structure of Shanghai;

(2) Input & output of energy;

(3) Secondary energy transformation;

(4) Final energy consumption by energy amount and energy carriers;

(5) Major energy consumers;

(6) Sector energy consumption, and pollutant and CO_2 emission;

(7) Change of energy structure, elasticity coefficient of energy consumption, and energy consumption for per unit GDP in Shanghai;

(8) Concentration of NOx and SO_2 in the ambient air.

1.5 Scenario Design

To predict the future energy demand and pollutant emission along with the economic growth of Shanghai, four scenarios are designed with assumed population, GDP growth, industrial structure, energy and environmental policies. These scenarios are Base Case Scenario (BC), Energy Policy Scenario (EP including Energy Efficiency Improvement, Energy Switch at Supply side, Expanding Gas Use), Environmental Policy Scenario including SO_2 Emission Control Target, NOx Emission Control Target, and PM_{10} Emission Control Target, as well as carbon emission tax scenario.

1.6 Output of Model Scenario

MARKAL and air quality model linked with Shanghai geographic information system (SGIS) is used for scenario analysis. Major outputs of this modeling are:

(1) Primary energy input

(2) Coal use

(3) Natural gas use

(4) Electricity capacity and production

(5) CO_2 emission

(6) SO_2 emission

(7) NOx emission

(8) PM_{10} emission

(9) Changing of pollutant exposure level.

1.7 Major Results

The major results of this study are summarized as follows:

(1) Energy consumption in Shanghai is increasing annually along with the high economic growth. In 1998, per capita energy consumption in Shanghai was 110 GJ, 1.17 times as much as that of national level.

(2) Coal is the major energy consumed, accounting for 70% of the total primary energy.

(3) SO_2 emission in 1998 of Shanghai was 489 kt, smoke and dust was 170 kt, NOx emission was about 40 kt, and CO_2 emission was 132 million ton.

(4) Due to the effectiveness of industry structure switching from industry center to commercial center, and lowing sulfur content in the fuel, pollution exposure level of SO_2 has been declined annually. However, current energy and environmental policies are ineffective in controlling NOx pollution.

(5) It is predicted that with the economic growth the GDP of Shanghai in 2020 will be 6.9~10.4 times as much as that of 1995. Energy demand of Shanghai will reach 1907-2744 PJ, 2.0~2.9 times as much as that of 1995, in which, industrial energy demand will be 3284~4754 PJ, 1.32~1.91 times as much as that of 1995; commercial energy demand will be 966~1846 PJ, 3.6~8.0 times as much as that of 1995; transportation demand will be 867~1310 PJ, 3.3~6.1 times as much as that of 1995; and domestic demand will be 123~187 PJ, 2.3~3.5 times as much as that of 1995.

(6) Under the energy policies, coal consumption will be declined from 67% in 1995 to 45% in 2020; raw oil will be increased from 31% in 1995 to 32%; natural gas will account for 21%; and 3% of electricity will come from other provinces.

(7) Under BC scenario, the CO_2 emission will reach to 230 Mt in 2020, and SO_2, NOx and PM_{10} emission will be higher than 950 kt, 840 kt, and 240 kt, respectively. SO_2, NOx and PM_{10} emission will be 90%, 120%, and 110% higher than that in 1995.

(8) With the energy switch from coal to gas, CO_2 emission in 2020 will be decreased from 230 Mt in BC scenario to 174 Mt in GAS2 scenario; SO_2 emission will be declined from 957 kt in BC to 464 Kt in GAS2. NOx emission will be decreasing from 848 kt in BC to 729 kt in GAS2. PM_{10} emission will be down from 243 kt in BC to 159 kt in GAS2. The emission reduction of CO_2, SO_2, NOx and PM_{10} will be 24%, 52%, 14% and 35% respectively in 2020.

(9) Under SO_2 emission control target scenario, SO_2 emission from Shanghai energy system will be deceased by applying end pipe technologies in order to achieve the

target. However, the co-benefit on CO_2 emission reduction of energy system can be neglected.

(10) If Shanghai want to improve local air quality by decreasing NOx pollution, more stringent vehicle emission standards, and vehicle inspection and maintenance (I/M) program have to be introduced as soon as possible. The introduction of stringent vehicle emission standards and I/M will not only play important role in reducing NOx emission, but will decease PM_{10} emission as well, because lower sulfur content in the fuel is required by the fuel specification.

(11) The co-benefit of carbon emission tax can be neglected except PM_{10}, if carbon emission tax added onward SO_2+NOx+PM_{10} emission control scenario. However, there will be some co-benefit on reduction of local air pollutant emission if carbon tax is to be added onward energy switch policy. It should be pointed out that the reduction of local air pollutant emission will largely depend on end pipe treatment.

(12) Under BC scenario, non-attainment area of SO_2 (Grade II criteria of national standard GB3095-1996: 0.06 mg/m^3) will reach 2448 km^2 in 2020, which will be 6.65 times higher than that in 2000. Non-attainment area of PM10 (Grade I criteria of national standard GB3095-1996: 0.04 mg/m^3) will reach 2080 km^2 in 2020, while there is no attainment area of primary PM10 in 2000.

(13) Under GAS2+SO_2 scenario, pollution of SO_2 will be decreased significantly that no more area will exceed the standard of SO_2 since 2005. However, the urban average concentration of PM_{10} will rise to 0.045 mg/m^3, which is 28.5% higher than that in 2000.

(14) Contributing to carbon emission tax added onward EFF+GAS1+GAS2+SO_2+ NOx1 scenario, co-benefit of PM_{10} pollution in ambient air will be achieved. The urban average of PM_{10} will reach 0.028 mg/m^3, being 15% lower than that of EFF+GAS1+GAS2+SO_2+ NOx1 scenario in 2020, and 20% lower than that in 2000.

1.8 Report Structure

This report comprises of 8 chapters. Chapter 1 is introduction, briefing the objectives of this study, project content, implementation and major conclusions. Chapter 2, 3 and 4 describe general social and economic conditions of Shanghai, energy supply and consumption features, and emissions. Chapter 5 is the analysis on the current status of local air quality in Shanghai. Chapter 6 is the analysis of future energy demand with economic growth. Chapter 7 provide a whole picture of emission reduction under specific energy and environmental scenarios. Chapter 8 shows the improvement of air quality with implementation of energy and environmental policies.

2. General Description of Social and Economic

2.1 Municipal and Population

Shanghai is china's largest port trade center and major open city, also is the one of highest population density cities in China. The total area is 6,340.5 km^2, with the urban area of 3248.7 km^2, accounting for 0.1% of the whole country.

表2-1　　上海市土地面积与人口

Table 2-1　　Land Area and Population

	单位 Unit	市区 Urban	县 County	全市 Total
土地面积 Land Area	(km^2)	3248.7	3091.8	6340.5
居民户数Households	(10 000)	378.79	86.93	465.72
年末人口 Population	(10 000)	1070.62	235.96	1306.58
平均每户人口 Average Persons per Household	(person)	2.83	2.71	2.81
人口密度 Density of Population	(person/km^2)	3296	763	2061

By the end of 1998, Shanghai had a population of 13.07 million, accounting for 1% of the whole country. The city's average population density was 2,061 persons per km^2, with the figure in the urban area standing at 3,296 persons per km^2, Nashi Districts reported the highest population density reached about 60,000 persons per km^2.

Even though the population growth rate has remained negative since 1993, with higher level of urbanization, the population from outside the city remains about 50,000 persons per year, the population of the whole city still increased smoothly.

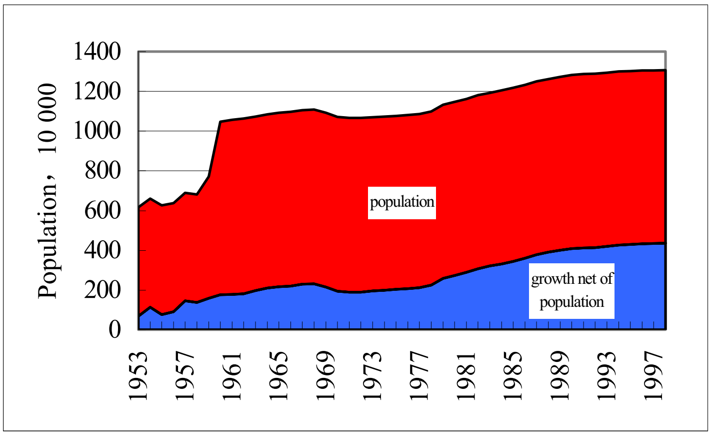

图 2-1　　全市人口增长

Figure 2-1　　Growth of population

2.2 General Description of Social and Economic

2.2.1 Gross Domestic Product

Because of its advantageous geographic location, the level of Shanghai's social and economic develop is higher than that of the nation's. From 1978 to 1989, the average annual growth rate of

GDP indices remained 8%. From 1990 to 1998, attained above 10%, see figure 1-4. Since several years, The GDP of Shanghai make up about 4% of the national total GDP, of which the industrial output value accounted for about 6% of the nation's, financial revenue accounted for 13% of the nation's.

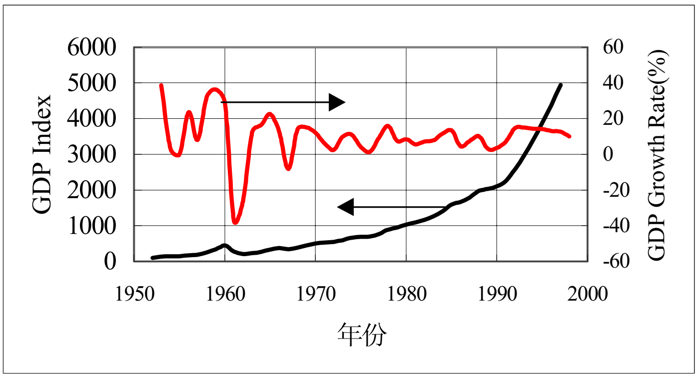

图 2-2　　上海市国内生产总值增长率波动情况

Figure 2-2　　Variation of GDP growth

The Shanghai's total gross domestic product in 1998 reached 368.82 billion RMB, of which the output value of primary, secondary, tertiary industry was 7.85 billion RMB, 184.72 billion RMB, 176.25 billion RMB respectively. The city's average GDP per capita first broke to 20,000 RMB in 1996, and then in 1998 reached 28,200 RMB.

2.2.2 Industrial Structure

Since 1980's, through transformation of municipality functions, the production with high energy consumption and low added value have been progressively phased out, the percentage of output value of services industry in GDP have gradually raised, the industrial structure have been readjusted. In 1975, the proportion of the output value of primary, secondary, tertiary industry in the GDP were respectively 4.0%, 77.4%, 18.6%, while in 1998 shift to 2.1%, 50.1%, 47.8%.

表2-2　　上海市产业结构变化　　单位：%

Table 2-2　　Composition of Shanghai GDP　　Unit: %

年份 Calendar Year	第一产业 Primary Industry	第二产业 Secondary Industry	第三产业 Tertiary Industry
1975	4	77	19
1980	3	76	21
1985	4	70	26
1990	4	64	32
1995	3	57	40
1998	2.1	50	47.8

2.3 Industrial Economy

2.3.1 Industry

2.3.1.1 Industry Composition

There are over 22,000 enterprises in Shanghai, of which 1482 factories were classed as large and medium. According to subordination, they are grouped to eight categories including central, city, district, county, neighborhood, town, country, village. According to registration, they are grouped to three categories including domestic investment, HK, Macro and Taiwan funded, foreign funded, of which domestic investment are grouped to eight categories including state-own, collective-owned, share holding, joint owned, companies with limited liabilities, stocking holding companies with limited liabilities, private.

In 1998, the industry output value of domestics investment enterprises accounted for 53% of the city's total, enterprises funded by HK, Macro and Taiwan accounting for 15%, foreign funded accounting for 32%. The ratio in the gross output value of industry of domestic investment enterprises to foreign funded enterprises was 1.12:1. The proportion of domestic enterprises among the gross output value of industry was slightly more than that of foreign funded enterprises.

2.3.1.2 Industry Category and Pillar industry

The industry categories in Shanghai is diverse, ranging from food production, textiles, petrol processing, chemical production, rubber products, plastic products, Smelting and processing of metals, machinery manufacturing, transportation equipment manufacturing, iron and steel, household appliance.

The city's six pillar industries namely auto, electronic telecommunications equipment, iron and steel, household appliances, power plant equipment, petrol-chemicals, fine chemicals and modern medicine manufacturing, reported a total output value of 244.74 billion RMB in 1998, accounting for the 41% of the city's total.

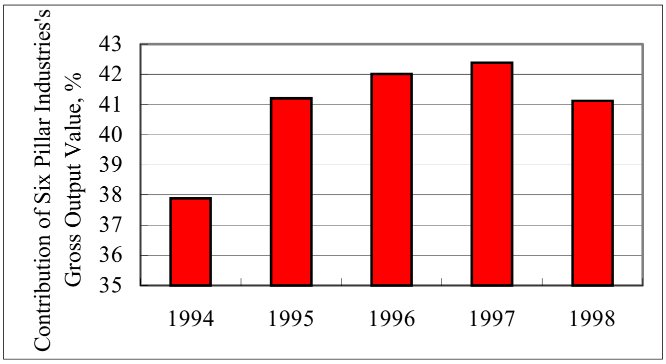

图 2-3　　全市六大支柱产业工业总产值比重

Figure 2-3　　Contribution of the Gross Output Value of Six Pillar Industries

2.3.1.3 Industry Production and Annual Output

With readjustment of the industrial structure, the production of light industry have been decreased progressively since 1990, the production of pillar industry products increased gradually.

表2-3　　　上海市主要工业产品产量

Table 2-3　　Production of Main Industrial Products

Name	Unit	1990	1995	1998
Bicycles	10 000	760.63	838.75	540.78
Cameras	10 000	20.62	153.23	428.58
TV Sets	10 000	465.50	418.23	200.94
Household Washing Machines	10 000	101.29	144.80	72.55
Household Refrigerators	10 000	53.36	128.72	38.61
Household Air-conditioners	10 000	1.83	62.46	113.98
Chemical Fibers	10 000 tons	25.74	37.83	40.93
Synthetic Fibers	10 000 tons	22.28	34.51	37.33
Paper and Paperboard	10 000 tons	46.49	39.97	45.46
Synthetic Detergent	10 000 tons	10.51	30.39	27.74
Pig Iron	10 000 tons	526.90	1048.38	1208.57
Steel	10 000 tons	914.62	1454.11	1603.75
Rolled Steel Final Products	10 000 tons	609.59	1185.89	1417.58
Sulfuric Acid	10 000 tons	40.04	31.03	35.59
Caustic Soda	10 000 tons	29.09	40.35	38.22
Ethylene	10 000 tons	21.95	40.83	50.36
Synthetic Ammonia	10 000 tons	41.24	43.74	25.10
Chemical Fertilizer	10 000 tons	28.85	29.56	12.73
Chemical Pesticides	10 000 tons	0.82	1.40	1.06
Tires	10 000	318.78	639.09	957.75
Cement	10 000 tons	230.30	433.22	330.95
Plate Glass	10 000 wt. cases	503.05	634.63	701.45
Plastic	10 000 tons	25.35	58.24	
Plastic Products	10 000 tons	19.54	38.38	28.19
Power Generating Equipment	10 000kw	210.20	496.50	403.85
Metal Cutting Machines	10 000	1.38	1.58	1.19
Motor Vehicles	10 000	2.81	16.27	23.64
Artificial Board	10000 cu.m	10.69	17.33	82.67
Tractors	10 000	0.77	1.52	1.38
Civil Steel Ships	10 000 tons	39.07	83.33	79.93

2.3.2 Transportation

2.3.2.1 Freight Transport

Cargo transport in 1998 totaled 462.3 million tons, of which goods and commodities handled by the railway system amounted to 52.92 million tons, that by the highway system amounted to 263.52 million tons, that by the navigable inland waterway system amounted to 96.85 million tons, that by the ocean shipping system amounted to 48.44 million tons, that by the airway amounted to 0.57 million tons. The turnover volume of freight traffic by the railway in the year totaled 11.7 billion tons· km, handled by the highways system were 4.9 billion tons · km, handled by the navigable inland waterway system were 87.1 billion tons· km, handled by the ocean shipping were 379.4 billion tons· km.

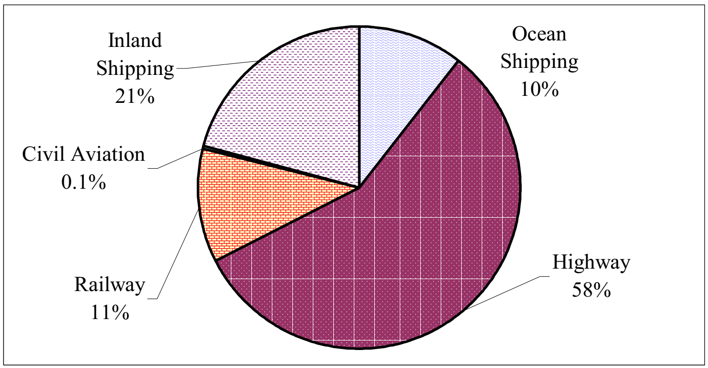

图 2-4　　1998 年上海市货物运输量

Figure 2-4　　Freight Traffic Volume of Shanghai, 1998

2.3.2.2 Urban Transportation

By the end of 1998, the city had 0.583 million motor vehicles, of which excluding scooters and mopeds with "C" license plate. The possession of motor vehicles in Shanghai was less than the other cities with the same scale in the world. Though recently new progress have been made in the city's road traffic, and the average road area per capita have gradually increased, owing to trading and dwelling highly density, the traffic in the core of city still was crowded.

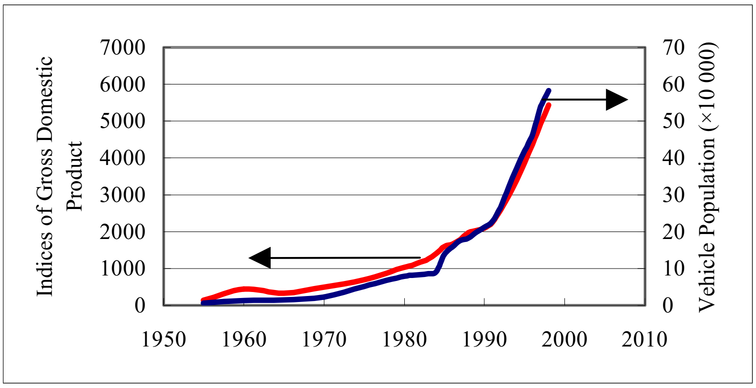

图 2-4 上海市机动车保有量

Figure 2-4　The Growth of Vehicle Population

Of the total motor vehicles, heavy duty vehicles accounted for 17.4%, light duty vehicles for 53.3%, motorcycles for 24.1%, motor vehicles of consulate and foreign funded enterprises respectively accounting for 1.0%, off road vehicles for 0.5%.

2.4 Living Standards

According to statistics from a sample survey, the average annual income per capita among urban residents increased from 2198 RMB in 1990 to 8825 RMB in 1998. Among the farmers, raised from 1990 RMB in 1990 to 5965 RMB in 1998. The top three of the city's expenditure was food, education, housing, respectively accounting for 42~51%, 11~12%, 10~21%.

The possession of durable consumer goods per 100 urban households, for example, electric fan, TV set, washing machine, refrigerator, air conditioner, microwave oven, and water heater, all were over 50. The possession of personal computer contiune to increase by a wide margin.

表2-4　　居民人均支出结构　　单位：%

Table 2-4　Structure of Household Expenditure　Unit: %

	Urban household			Rural household		
	1990	1995	1998	1990	1995	1998
Food	57	53	51	47	44	42
Clothing	11	10	7	9	7	6
Housing	5	6	10	22	23	21
Household facilities	9	11	7	10	8	9
Medicine and medical services	1	2	4	3	2	4
Traffic and telecommunication	3	5	6	1	5	5
Education	12	8	12	5	8	11
Others	4	5	5	4	3	2

表2-5　　居民耐用品拥有量　　单位：台/百户居民

Table 2-5　Household　Possession of Durable Consumer　Unit: units/100 household

	Urban household			Rural household		
	1990	1995	1998	1990	1995	1998
Electric fans	187	216	229	204	270	308
Color TV sets	77	109	128.2	25	49	74
Black TV sets				74	75	68
Refrigerator	88	98	103	29	56	72
Washing machine	72	78	91.6	45	63	66
Radio	100	89	82.2	27	39	42
Recorder				27	36	41
Air conditioner		33	68.6		1	7
Microwave oven		33	62.8			7
Water heater		37	53.8			29
Video recorder	14	49	48.8		9	9
VCD player			25.4			8
Computer		2.2	13.2			
Scooter		4.8	13	1	22	55
Moped and motorcycle		0.8	1.4			

3. Energy Supply and Consumption

3.1. Energy Inflow and Outflow

Shanghai is a municipality that is lack of energy resources. Its economy development mainly depends on energy delivered from other provinces in China. In accordance with the Year Book of Shanghai, in 1998 the volume of energy which was delivered from other province was 1806 PJ, while 383 PJ was transported to other province. The total volume of usable energy was 1436 PJ (Table 3-1).

表3-1　　1995-1998 年上海市能源调入与调出量　　单位：PJ

Table 3-1　　Energy import and export of Shanghai　Unit: PJ

Year	Import	Export	Storage	Consumption
1990	1239.2	-306.9	12.2	944.5
1995	1580.0	-267.8	0.6	1312.8
1998	1805.9	-383.3	13.8	1436.4

3.1.1 Energy Inflow and Composition

According to the energy resources in China, the main energy supplied in Shanghai is coal and then crude, while the secondary energy constitutes the minority.

In reference with statistic material for 1995~1998, coal accounts for 56%~62% of total energy supplied, of which raw coal and coking coal constitutes 39%~43% and17%~19% respectively, while crude oil accounts for 24~27% of total energy supplied. The primary energy and secondary energy account for 80%~87% and 12%~20% of total energy supplied.

表3-2　　1995-1998 年上海市能源调入量与调入品种　　单位：%

Table 3-2　　Energy Carriers Import, 1995-1998　　Unit: %

能源调入品种	Energy Carriers Import	1995	1998
原煤	Coal	38.2	38.8
洗精煤	Coking Coal	17.5	17.8
原油	Crude Oil	25.6	23.2
焦炭	Coke	1.3	0.5
汽油	Gasoline	1.7	2.2
煤油	Kerosene	1.5	1.7
柴油	Diesel	3.0	5.8
燃料油	Fuel Oil	3.4	6.1
LPG	LPG	0.3	0.3
其他石油产品	Other Petro-products	0.4	0.0
电力	Electricity	1.1	1.0
其他	Others	6.0	2.5
合计	Total	100	100

3.1.2 Energy Outflow and Composition

Energy outflow in Shanghai is 268~383 PJ per year for 1995~1998, of which finished oil (gasoline, kerosene and diesel) and other petro-product account for the main proportion and raw coal, other coking product and fuel oil rank orderly.

Primary energy outflow accounted for 7%~11% of the total energy outflow during 1995~1998, of which raw coal outflow accounted for 6%~11% (with increasing trend) and crude oil was scarcely delivered to other provinces (expect for year 1995). Secondary energy outflow accounted for 89%~92%, of which finished oil accounted for 39%~49% (with increasing trend), fuel oil accounted for 5%~11%,other pero-product accounted for 16%~26% (with decreasing trend) and electricity accounted for 4%~6%.

表3-3 1995-1998 年上海市能源调出量与调出品种 单位：%

Table 3-3 Energy Carriers Export, 1995-1998 Unit: %

能源品种	Energy Type	1995	1998
原煤	Coal	6.0	11.4
原油	Crude Oil	2.0	0.0
焦炭	Coke	0.0	3.4
焦炉煤气	Coke Gas	0.7	0.5
汽油	Gasoline	14.8	17.5
煤油	Kerosene	6.4	6.8
柴油	Diesel	17.8	24.8
燃料油	Fuel Oil	6.7	4.9
LPG	LPG	2.3	1.7
其他石油产品	Other Petro-products	26.5	15.5
其他焦化产品	Other Coking Products	0.0	2.2
电力	Electricity	6.0	4.4
其他	Others	10.7	7.0
合计	Total	100	100

3.1.3 Usable Energy

According to the Year Book, the total volume of usable energy was 1436 PJ in 1998, 10% higher than that in 1995 (1313 PJ), of which coal inflow and crude oil accounted for 69% and 30% respectively.

表3-4　　1995~1998 年上海市可供消费能源　单位：%

Table 3-4　Shanghai Energy Inflow and Outflow, 1995~1998　Unit: %

能源品种	Energy Carries	1995	1998
原煤	Coal	45.7	46.9
洗精煤	Coking Coal	21.6	22.6
焦炭	Coke	1.3	-0.5
焦炉煤气	Coal Gas	-0.1	-0.1
其他煤气	Other Gas	1.6	0.8
原油	Crude Oil	31.1	29.9
汽油	Gasoline	-1.1	-2.5
煤油	Kerosene	0.1	0.4
柴油	Diesel	-0.2	0.6
燃料油	Fuel Oil	2.5	6.5
液化石油气	LPG	-0.2	0.0
炼厂干气	Dry Gas	0.0	0.0
其他石油产品	Other Petro Products	-5.6	-4.4
其他焦化产品	Other Coke Products	0.0	-0.7
热力	Heat	0.0	0.0
电力	Electricity	-0.1	0.0
其他能源	Others	3.3	0.4
合计	Total	100	100

3.2. Energy Processing

3.2.1 Electricity Production

(1) Capacity of Power Plant

The total capacity of power plants in Shanghai increased with years for 1995~1998. By the year 1998, there were 16 power plants in Shanghai of which the total capacity reached 8.37 GW. Among these 16 power plants, Shidongkou power plant, Waigaoqiao power plant and Huaneng Shidongkou No.2 power plant have the highest capacity of 1.20 GW, Wujing heat and power plant and self-provided power plant for Bao Steel have the capacity of 950 and 850 MW respectively, the other power plants have the capacity of less than 400 MW (see Table 3-5).

(2) Electricity Production

Electricity production increased with years together with the development of economy and improvement of living level. Electricity production increased by 6.4% every year for the period 1990~1998 (Table 3-6). Electricity production reached 482.2 Twh.

表3-5　　　1990~1998 年上海市电力生产量

Table 3-5　Shanghai Power Generation, 1990-1998

年份 Year	亿千瓦时 100 Mkwh	皮焦耳 PJ	年递增率 Annual Increment %
1990	284.10	102.16	2.1
1995	403.42	145.07	1.0
1998	482.16	173.38	5.2

(3) Energy Consumed in Power Generation

According to the statistics of energy consumption for 1995-1998, raw coal consumption for power generation accounted for 57%~59% of usable raw coal in Shanghai. Energy consumption in power generation reached 445 PJ, of which raw coal consumption reached 393 PJ and other secondary energy consumption reached 52 PJ (Table 3-7).

表3-6　　　1990~1998 年上海市电力生产的能源消费量

Table 3-6　Energy Consumption of Power Generation, 1990-1998

年份 Year	发电量 Power Generation		发电用能，皮焦耳 Energy Consumption, PJ		
	亿千瓦时 100 MkWh	皮焦耳 PJ	原煤 Coal	其它 Others	合计 Total
1990	284.10	102.16	226.8	63.0	289.8
1995	403.42	145.07	342.9	49.7	392.6
1998	482.16	173.38	393.0	52.0	444.9

According to the statistics, energy consumption per unit electricity production decreased with years. It was 348 g SCE/kWh in 1990 and 334 g SCE/kWh in 1998 (Figure 3-8).

(4) Efficiency of Power Generation

According to the statistics of power generation efficiency for 1990~1998 from Planning Committee, the efficiencies for 1990, 1995 and 1998 are 36%, 37% and 38% respectively. The efficiency of power generation increased with years.

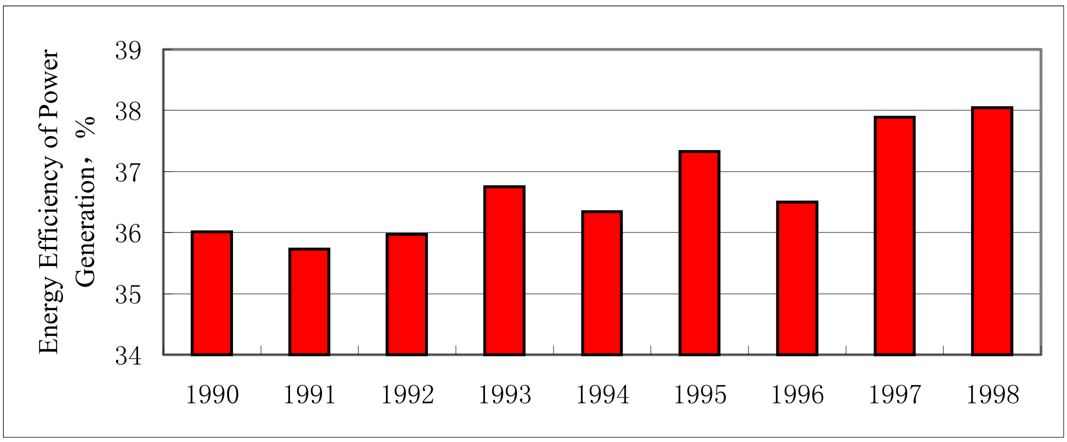

Figure 3-1　The Efficiency of Power Generation, 1990~1998

3.2.2 Heat Production

There are 6 heat and power plants in Shanghai including Yangshupu, Nanshi, Wujing, Jinshan, Gaoqiao and Xinghuo plant. The total capacity of heat generation for 1995 and 1998 were 103.7×10^4 kW and117.67×10^4 kW, the quantity of heat generated were 45.6 PJ and 41.7 PJ. Energy consumption per unit heat production were 39~40 kg SCE/MkJ.

表3-7 上海市热力生产投入产出 单位：PJ

Table 3-7 Input and output of heat production, 1995-1998 Unit: PJ

能源		Energy Carries	1995	1998
投入 Input	原煤	Coal	41.91	42.41
	柴油	Diesel	0.00	0.18
	燃料油	Fuel Oil	10.08	5.90
	投入合计	Total input	51.99	48.49
产出 Output	产出热力	Heat Production	45.61	41.65
效率 Efficiency，%		Efficiency, %	87.7	85.9

3.2.3 Coke and Gas Production

(1) Coke Production

According to the statistics for 1995~1998, coking coal consumption in the coke production increased with years. The total coking coal consumption in 1998 was 252 PJ, with which 246 PJ of secondary energy was produced. The secondary energy included 186 PJ of coke, 44 PJ of coke-oven gas and 16 PJ of other coking production. The ratio of output to input kept at 0.96~0.98.

表3-8 1995~1998 年上海市焦炭生产的能源消费量 单位：PJ

Table 3-8 Energy Input and Output of Coke Production, 1995-1998 Unit: PJ

投入/产出	能源载体	Energy Carriers	1995	1998
投入，Input	洗精煤	Coking Coal	238.3	252.3
产出 Output	焦炭	Coke	176.5	185.6
	焦炉煤气	Coke Gas	41.3	43.8
	其它焦化产品	Other Coke Products	15.3	16.4
	合计	Total Output	233.1	245.8
能源加工转换效率		Energy Efficiency	97.8%	97.4%

(2) Gas Production

Energy input for gas production was 51 PJ in 1998, of which the consumption of raw coal, coking coal coke-oven gas, fuel and heat were 12 PJ (23%), 21 PJ (41%), 8.3 PJ (16%), 8.9 PJ (17%) and 1.3 PJ (2.5%) respectively. The amount of secondary energy produced in gas production was 43 PJ, of which coke, gas, other coking product accounted for 9.5 PJ (22%), 29 PJ (68%) and 4.5 PJ

(10%). The energy production efficiency kept up 80% despite its instability (See Table 3-10).

表3-9　　1995~1998 年煤气生产的能源消费量　　单位：　PJ

Table 3-9　Energy Consumption of Gas Production, 1995-1998 Unit: PJ

	能源	Energy Carriers	1995	1998
投入 Input	原煤	Coal	5.55	11.85
	洗精煤	Coking Coal	21.08	20.84
	焦炉煤气	Coke Gas	9.94	8.26
	燃料油	Fuel Oil	9.24	8.88
	热力	Heat	1.04	1.28
	合计	Total	46.84	51.11
产出 Output	焦炭	Coke	7.94	9.49
	煤气	Gas	31.42	29.37
	焦化产品	Coke Products		4.48
	其它	Others	0.00	0.00
	合计	Total	39.36	43.34
能源加工转换效率		Efficiency	84.02%	84.79%

3.2.4 Oil Process

(1) Crude Oil Process

The amount of crude oil processed was 428 PJ in 1998. The crude oil is mainly used in oil process and production. At present, the main crude oil processing enterprises are Shanghai Oil Factory and Shanghai General Oil Chemical Factory ect.. The overall oil products was 418 PJ, of which petrol, diesel, kerosene, fuel oil, LPG, dry gas and other oil products accounted for 22%, 23%, 5%, 2%, 7%, 7% and 35%.

表3-10　　1995~1998 年全市原油加工产品与产量　　单位：PJ

Table 3-10　　Input and output of oil refinery, 1995-1998　　Unit: PJ

能源	Energy Carries	1995	1998
原油	Crude Oil Input	-400.4	-428.1
汽油	Gasoline	48.3	79.8
煤油	Kerosene	15.5	18.3
柴油	Diesel	54.4	83.7
燃料油	Fuel Oil	119.9	57.7
液化石油气	LPG	20.9	24.2
炼厂干气	Dry Gas	21.7	26.3
其它石油产品	Other Petro Products	112.0	127.6
石油产品合计	Total Output	392.6	417.6
原油加工效率	Oil Refinery Efficiency, %	98.1	97.6

3.3. End-Energy Consumption in Shanghai

3.3.1 Primary Industry

Energy consumption of primary industry kept at 15~22 PJ for the period 1996~1998. Energy consumption of primary industry accounted for 2% of the total end-energy consumption in Shanghai in 1998, of which raw coal, gasoline, diesel and electricity accounted for 12%, 36%, 36% and 15%. The primary energy consumption in primary industry increased in 1998 as compared with that in 1995, while the secondary energy consumption decreased, especially the electricity consumption (it decreased from 28% in 1995 to 12 in 1998), see Table 3-12.

表3-11　　1995~1998 年全市第一产业能源消费品种及消费量 单位：PJ
Table 3-11　　Energy Consumption of Primary Industry, 1995-1998　　Unit: PJ

能源品种	Energy Carries	1995	1998
原煤	Coal	0.18	2.54
汽油	Gasoline	5.88	7.70
煤油	Kerosene	0.00	0.02
柴油	Diesel	4.96	7.84
液化石油气	LPG	0.04	0.10
其它石油产品	Other Oil Products	0.08	0.20
电力	Electricity	4.28	3.24
合计	Total	15.42	21.64

3.3.2 Secondary Industry

The secondary industry includes industry and construction industry according to the statistic method in China. Great adjustment of industry structure had been taken place in 90's of 20 century, i.e. change to "tertiary, secondary, primary" trends. Therefore the energy consumption of secondary industry has seen a great change accordingly. It's proportion in the total energy consumption decreased from 78.9% in 1995 to 70.5% in 1998. However, the secondary industry is still the major energy consumer.

(1) Energy Consumption of Industry

The end-energy consumption of industry decreased from 789 PJ (78%) in 1995 to 749 PJ (70%) in 1998.

表3-12　　1995~1998 年全市工业能源消费品种及消费量与消费结构

Table 3-12　　Energy Consumption of Industry, 1995~1998

能源品种	Energy Carries	皮焦耳，PJ		能源消费结构，%	
		1995	1998	1995	1998
原煤	Coal	150.38	156.2	19.1	20.9
洗精煤	Coking Coal	19.35	43.3	2.5	5.8
焦炭	Coke	196.49	188.0	24.9	25.1
焦炉煤气	Coke Gas	29.02	31.3	3.7	4.2
其他煤气	Other Gas	40.96	4.3	5.2	0.6
原油	Oil	8.31		1.1	0.0
汽油	Gasoline	11.44	5.8	1.4	0.8
煤油	Kerosene	0.57	0.4	0.1	0.1
柴油	Diesel	9.87	10.3	1.3	1.4
燃料油	Fuel Oil	65.26	54.5	8.3	7.3
液化石油气	LPG	8.64	10.6	1.1	1.4
炼厂干气	Dry Gas	20.82	24.2	2.6	3.2
其他石油产品	Other Oil Products	36.90	56.7	4.7	7.6
其他焦化产品	Other Coke Products	15.33	11.3	1.9	1.5
热力	Heat	41.90	37.2	5.3	5.0
电力	Electricity	101.89	114.6	12.9	15.3
其他能源	Others	32.24	0.4	4.1	0.1
合计	Total	789.4	749.1	100	100

(2) Energy Consumption of Construction Industry

Construction industry developed rapidly for recent years. The energy consumption of construction industry increased with year during the period 1995~1998. It increased from 8.2 PJ (0.8%) in 1995 to 18 PJ (1.6%) in 1998, i.e. increased by 1.2 times. The main energy carries consumed are diesel and electricity. The consumption of these two carries are 8.3 PJ and 2.6 PJ, which accounted for 47% and 15% of total energy consumption in construction respectively.

表3-13 1995~1998 年全市建筑业能源消费品种及消费量

Table 3-13 Energy Consumption of Construction Sector, 1995~1998

能源品种	Energy Carries	皮焦耳，PJ		能源消费结构，%	
		1995	1998	1995	1998
原煤	Coal	0.24	2.2	2.9	12.4
洗精煤	Coking Coal	0.00		0.0	0.0
焦炭	Coke	0.04		0.5	0.0
其他煤气	Other Gas	0.00		0.0	0.0
汽油	Gasoline	0.65	3.8	7.9	21.3
煤油	Kerosene	0.00	0.1	0.0	0.6
柴油	Diesel	3.96	8.3	48.4	46.6
燃料油	Fuel Oil	0.44	0.0	5.4	0.0
液化石油气	LPG	0.11	0.2	1.3	1.1
其他石油产品	Other Oil Products	0.07	0.6	0.9	3.4
热力	Heat	0.12		1.5	0.0
电力	Electricity	2.56	2.6	31.3	14.6
合计	Total	8.19	17.7	100	100

3.3.3 Tertiary Industry

The tertiary industry includes transportation, storage, postal and telecommunication, retail and wholesale business and catering trade. Energy carries consumed in transportation are main petrol and diesel, consumed in postal and telecommunication and retail and wholesale business etc. are main electricity, consumed in catering trade are main gas, electricity and raw coal. Storage is the largest energy consumer within the tertiary industry.

Energy consumption in tertiary industry was 199 PJ in 1998, which accounted for 18.3% of the end-energy consumption in Shanghai and increased by 6.1% as compared with 1995 (12.2%). The main energy carries consumed in the tertiary industry are diesel, fuel oil, electricity, kerosene, petrol and gas, of which the consumption accounted for 31%, 22%, 14%, 12%, 11% and 3% respectively. While the consumption raw coal accounted for 1.5%.

表3-14　1995 和 1998 年全市第三产业能源消费品种及消费量　　单位：皮焦耳

Table 3-14　Energy Consumption of Tertiary Industry, 1995 and 1998 Unit: PJ

能源品种	Energy Carriers	1995				1998			
		（1）	（2）	其他	小计	（1）	（2）	其他	小计
原煤	Coal	0.69	4.44	1.33	6.47	2.59	0.26	0.22	3.07
洗精煤	Coking Coal	0.00	0.17	0.08	0.25	0.00	0.00	0.00	0.00
焦炉煤气	Coal Gas	0.00	0.00	0.05	0.05	0.00	0.34	0.11	0.45
其他煤气	Other Gases	0.00	0.01	2.53	2.54	0.00	3.10	2.75	5.86
汽油	Gasoline	3.89	0.13	10.38	14.39	5.76	1.15	15.27	22.18
煤油	Kerosene	15.55	0.00	0.00	15.55	23.17	0.01	0.33	23.52
柴油	Diesel	28.20	1.43	2.50	32.13	54.90	4.17	3.67	62.74
燃料油	Fuel Oil	31.33	0.06	0.41	31.81	39.56	0.06	4.15	43.77
液化石油气	LPG	0.00	0.93	0.62	1.55	0.08	2.03	1.67	3.78
其他石油产品	Other Oil Products	0.48	0.00	0.76	1.25	1.91	0.91	2.39	5.21
热力	Heat	0.00	0.00	0.21	0.21	0.00	0.00	0.62	0.62
电力	Electricity	1.62	4.78	10.52	16.92	2.66	7.53	17.78	27.97
合计	Total	81.75	11.96	29.38	123.10	130.64	19.57	48.97	199.17

(1)　transportation, storage, postal and telecommunication

(2)　wholesale, retail sales and catering trade

3.3.4 Energy Consumption for Living

Energy consumption for living was 99 PJ in 1998, which accounted for 9.2% of end-energy consumption in Shanghai and increased by 1.8% compared with 1995 (7.4%). The main energy carries consumed are raw coal, gas, LPG and electricity, which accounted for 46%, 18%, 10% and 16.5% respectively, see Table 3-16.

Per capita energy consumption was 7609 MJ in Shanghai in 1998 which was 1.3 times as that in 1995 (5721MJ). Per capita electricity consumption for living in 1998 was 348 kWh which was 1.5 times as that in 1996 (233 kWh). Per capita energy consumption for cooking (gas and LPG) was 2090 MJ, see Table 3-17.

The total electricity consumption in Shanghai (including urban and rural area) was 45.5×10^{8} kWh. Electricity consumption of urban and rural households was 38.9×10^{8} kWh and 6.56×10^{8} kWh, which was 1.6 times and 1.2 times as compared with those in 1995 (24.9×10^{8} kWh and 5.37×10^{8} kWh).

表3-15 1995~1998 年全市生活能源消费品种及消费量

Table 3-15 Residential Energy Use, 1995~1998

能源品种	Energy Carries	皮焦耳，PJ		能源消费结构，%	
		1995	1998	1995	1998
原煤	Coal	43.9	45.4	58.9	45.7
洗精煤	Coking Coal	0.0	0.1	0.0	0.1
焦炭	Coke	0.0	0.1	0.0	0.1
焦炉煤气	Coal Gas	0.5	0.8	0.7	0.8
其他煤气	Other Gas	8.4	17.0	11.3	17.1
汽油	Gasoline	1.3	5.0	1.7	5.0
煤油	Kerosene	0.1	0.1	0.1	0.1
柴油	Diesel	0.9	2.5	1.2	2.5
液化石油气	LPG	8.4	9.5	11.3	9.6
其他石油产品	Other Petro Products	0.1	1.5	0.1	1.5
热力	Heat	0.0	1.0	0.0	1.0
电力	Electricity	10.9	16.4	14.6	16.5
合计	Total	74.5	99. 4	100	100

表3-16 1995~1998 年全市人均生活能源用能

Table 3-16 Residential Energy Use Per Capita, 1995~1998

能源品种	Energy Carries	人均生活能耗，MJ per Capita	
		1995	1998
原煤	Coal	3374.6	3476.2
洗精煤	Coking Coal	0.0	9.6
焦炭	Coke	0.0	11.2
焦炉煤气	Coal Gas	38.7	59.2
其他煤气	Other Gas	644.1	1300.3
汽油	Gasoline	101.1	385.8
煤油	Kerosene	6.3	6.3
柴油	Diesel	68.2	188.9
液化石油气	LPG	644.3	729.2
其他石油产品	Other Petro Products	6.1	112.8
热力	Heat	0.0	75.1
电力	Electricity	838.0	1253.9
合计	Total	5721.5	7608.7

3.3.5 Energy Consumption in Transportation

(1) Vehicle Population and GDP

The vehicle population was 1330,000 in 1998, according to the World Bank – Shanghai Municipality Transportation Project “Reduction strategy of vehicle emission in Shanghai” (1996), Shanghai Sciences and Technology Committee “control target for vehicle emission in Shanghai”

(1997.5), Shanghai Steering Group for Comprehensive Control of Vehicle Emission "comprehensive prevention and control plan for vehicle emission in Shanghai" (2000.2) and Shanghai Environment Protection Bureau "Pollution sources investigation and contribution ratio study for NOx in Shanghai"（2000.4）etc.. The population of on-road and off-road vehicles were 1320,000, and 10,000 respectively, of which heavy vehicle, light vehicle, off-road vehicle accounted for 6.9%, 23.4% and 0.7% respectively, while the amount of motorcycle, motor scooter and moped accounted for 70%.

According to the statistics, the increment of vehicle population synchronized with that of GDP for the years past, see figure 3-2.

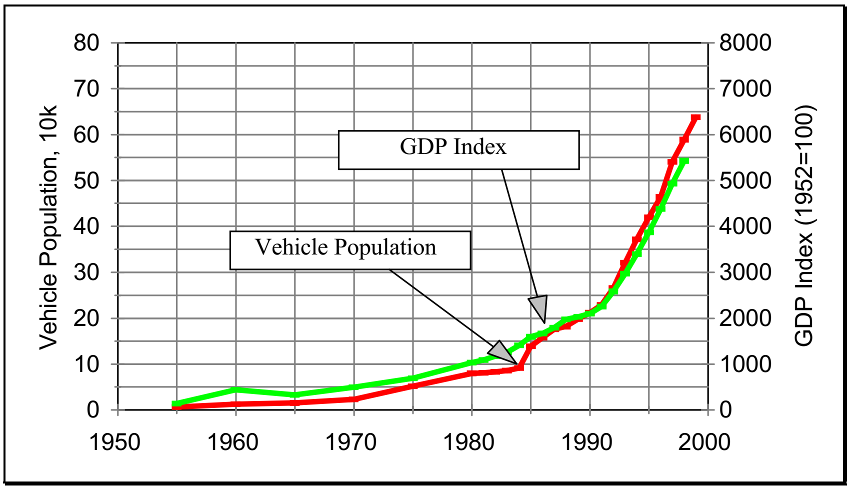

Figure 3-2　　Vehicle Population and GDP Index Growth

(2) Energy Consumption in Traffic

With reference to the oil consumption per 100 km and miles of route of various kinds of vehicle, the fuel consumption of on-road vehicles were 63 PJ and 78 PJ for 1995 and 1998 respectively. The consumption of petrol and diesel were 42 PJ and 11 PJ.

The energy consumed in traffic accounted for 6.3% and7.1% of the total amount of end-energy consumption in Shanghai for 1995 and 1998.

表3-17　1995~1998 年全市各种车辆交通用能

Table 3-17　　Transportation Energy Use for Different Type Vehicles, 1995~1998

车辆类型	Vehicle Type	皮焦耳，PJ		能源消费比重，%	
		1995	1998	1995	1998
大型车	Heavy Duty Vehicles	22.58	23.55	35.7	30.3
小型车	Light Duty Vehicles	37.92	50.24	60.0	64.7
摩托车	Motorcycle and Mopeds	2.75	3.91	4.3	5.0
合计	Total	63.3	77.7	100	100

3.4　Main Energy Consumers

3.4.1 Main Energy Consumers of Raw Coal

The main energy consumers of raw coal are power plant, iron and steel manufacturing, petroleum and chemical industry, coking enterprise, cement manufacturing and gas production etc.. The consumption of raw coal for these sectors accounted for 72% of the total amount of raw coal consumption in 1998. The power plant, iron and steel manufacturing, petroleum processing, chemical industry, coking enterprise, cement manufacturing, gas production, fertilizer production, vehicle manufacturing, tire and rubber accounted for 58%, 5.7%, 3.9%, 1.9%, 1.6%, 1.3%, 0.6%, 0.3%, 0.2% and 0.1%.

3.4.2 Main Coking Coal Consumers

The main coking coal consumers are iron and steel manufacturing, coking and gas production sectors etc.. The consumption of coking coal in steel manufacturing, coking and gas production accounted for 61%, 18% and 6%. The coking coal consumption in these three sectors accounted for 85% of the amount consumed in Shanghai in 1998, while other sectors accounted for only 13%.

3.4.3 Main Coke Consumers

The amount of coke produced for 1998 was199 PJ, of which 14 PJ of coke was delivered to other provinces. The inflow of coke in 1998 was 8.6 PJ. Totally, the amount of coke consumed in Shanghai was 192 PJ. The main coke consumer is iron and steel manufacturing, of which the coke consumption accounted for 88%. While chemical, coking and gas production sectors accounted for 2.6% individually. The total coke consumption for the sectors mentioned above accounted for 96% of the total amount consumed in Shanghai.

3.4.4 Main Gas Consumers

The total gas consumption in Shanghai in 1998 was 120×10^8 m^3, of which 105×10^8 m^3 of gas was consumed in secondary industry and 15×10^8 m^3 was consumed in tertiary industry and living.

The main gas consumers are iron and steel, chemical, vehicle manufacturing, metal process and machinery manufacturing etc.. The gas consumption for these sectors accounted for at least 80% of the amount consumed in Shanghai.

3.4.5 Main Fuel Oil Consumers

The consumption of fuel oil in 1998 was 151 PJ, of which 52 PJ was consumed in secondary energy processing, 98 PJ was consumed as end-energy and 0.7 PJ was balance. The main fuel oil consumers are the tertiary industry, petroleum chemical industry, power plant, iron and steel manufacturing, gas production and glass production etc., of which the fuel oil consumption accounted for 29%, 22%, 17%, 11%, 9% and 5% of the total amount consumed in Shanghai respectively. The fuel oil consumption of the above sectors accounted for 93% in total.

3.5 Energy Balance for Shanghai

With reference to Shanghai energy statistics for 1995~1998, the energy inflow was 1806 PJ in 1998. The energy outflow, net storage and the usable energy was 383 PJ, 14 PJ and 1436 PJ respectively, which accounted for 21%, 0.8% and 80% of the energy inflow.

Energy used as the input for the secondary energy production in 1998 accounted for 22% of the total energy consumed in Shanghai in 1998. The energy consumed in the primary, secondary, tertiary industries and residential living accounted for 1.5%, 53.4%, 14% and 7% respectively.

The amount of energy consumed in Shanghai increased for the period 1995~1998. In comparison with 1995, the energy inflow, energy outflow and usable energy, increased by 14%, 43% and 9% respectively. The energy consumed in the secondary energy processing increased by 13%. The energy consumed in the primary industry, construction, the tertiary industry and residential living increased by 40%, 116%, 62% and 34% respectively, while the energy consumed in industry decreased by 5% compared with 1995. In spite of this, the industry is still the largest energy consumer in Shanghai.

表3-18　　1995~1998 年上海市能源消费平衡表

Table 3-18　　Shanghai Energy Balance, 1995~1998

部门	Sectors	皮焦耳，PJ		能源消费结构，%	
		1995	1998	1995	1998
可供资源量	Total Supply	1312.8	1436.4	83.1	79.5
调入量	Inflow	1580.0	1805.9	100	100
调出量	Outflow	-267.8	-383.3	16.9	21.2
库存差	Storage	0.6	13.8	0.0	0.8
消费总量	Total Consumption	1312.8	1436.4	100	100
二次能源加工净消费量	Energy Consumption for Secondary Energy Production	274.2	309.5	20.9	21.5
损失量	Loss	26.3	31.7	2.0	2.2
第一产业	Primary Industry	15.4	21.6	1.2	1.5
农业	Agriculture	15.4	21.6	1.2	1.5
第二产业	Secondary Industry	797.6	766.8	60.7	53.4
工业	Industry	789.4	749.1	60.1	52.2
建筑业	Construction	8.2	17.7	0.6	1.2
第三产业	Tertiary Industry	123.1	199.2	9.4	13.9
交运及邮电	Post and Communication	81.8	130.6	6.2	9.1
批发零售贸易	Wholesale and Retails	12.0	19.6	0.9	1.4
其它	Others	29.4	49.0	2.2	3.4
生活	Residential Use	74.5	99.4	5.7	6.9
平衡差	Balance	1.8	8.1	0.1	0.6

4. CO_2 and Pollutant Emission in Energy Consumption

4.1 The Energy Consumption of Various Combustion Processes in Shanghai

According to energy consumption statistic data of Shanghai from 1995 to1998, the energy consumption of second energy processing transfer was 1231 PJ in 1998. Of which, the energy net input of firepower generation is 445 PJ, that of heating production, coke making and oil refining is 48 PJ, 51 PJ, and 434 PJ, respectively.

The energy processing transfer provides 845 PJ of second energy. Of which, electric power provides 174 PJ (i.e. 48,24 billion kilowatt hour), heating power 42 PJ, coke 195 PJ, coal gas 73 PJ (i.e. 4 billion cubic meters), various kinds of finished product oil (includes gasoline, diesel oil and kerosene)181 PJ, fuel oil 58 PJ, LPG 24 PJ, other petroleum products 127 PJ, other coking products 21 PJ.

表4-1　　1995~1998 年上海市能源加工转换与终端能源消费　　单位：PJ

Table 4-1　Energy Transformation and End Use, 1995~1998　Unit: PJ

用能部门	Sectors	1995	1998
1. 加工转换纯投入	1. Processing Transfer Input	1130.06	1230.82
1.1 火力发电	1.1 Power Generation	392.57	444.92
1.2 供热	1.2 Heat Production	51.99	48.49
1.3 炼焦	1.3 Coke Making	238.30	252.32
1.4 炼油	1.4 Oil Refining	400.35	433.98
1.5 制气	1.5 Gas Making	46.84	51.11
2. 损失量	2. Loss Volume	26.33	31.73
3. 终端消费量	3. End use	1010.54	1087.06
3.1 第一产业	3.1 Primary Industry	15.42	21.64
3.2 第二产业	3.2 Secondary Industry	797.56	766.84
3.3 第三产业	3.3 Tertiary Industry	123.10	199.17
3.4 生活消费	3.4 Residential Consumption	74.45	99.41
4. 平衡差	4. Balance	1.78	8.14

4.2 The Pollutant Emission Factors in Various Combustion

To calculate CO_2 and pollutant emission in various combustion and technological processes in Shanghai, the study has collected the pollutant factors of different fuel unit in power plants, industrial boilers, energy equipment for business and resident, steel manufactures.

The collected information indicates that SO_2 emission is decided by sulphur quantity in fuel and varies among different boilers. NOx emission is interrelated with factors such as air excess factor, load factor, combustion temperature, etc.. The emission factor of the combustion equipment using different fuel differs great.

Because fuel types, combustion mode, control condition and boiler tonnage of the combustion equipment are different. So in the course of identifying CO_2 and pollutant emission coefficients of various energy-consuming equipment, it is need to lookup Air Chief pollutant and CO_2 emission coefficient databank provided by U.S EPA to check the accuracy of information.

Selecting Air Chief searching results according to boiler type, fuel type and pollutant quantity of fuel to calculate SO_2, NOx and CO_2 of different sectors. Replace absent emission factors in Shanghai with average value of Air Chief searching results.

表4-2　　电厂不同燃烧机组污染物排放量　单位：kg/billion kWh

Table 4-2　Pollutants Emissions Factors of Different Power Generation Cycles Unit: kg/ B kWh

污染物 Pollutants	天然气机组 Natural Gas Cycle	燃油机组 Fuel Oil Cycle	燃煤机组 Coal Burning Cycle
SOx	0.27	376.5-417.3	299-1996
Smoke	2.27-6.80	63.5-326.6	27.2-4280
CO	7.7-9.1	18.1	20-40
HC	0.45-3.60	3.2	5.9-20
NOx	36.3-317.5	59-344.7	304-1100

表4-3　　燃烧 1 吨煤炭的污染物排放量单位：kg/t

Table 4-3　Pollutants Emissions Factors of Different Boilers　Unit: kg/t coal

污染物 Pollutants	电厂锅炉 Power Station Boilers	工业锅炉 Industrial Boilers	采暖炉或家用炉 Heating Boilers or Residential Boilers
CO	0.23	1.36	22.7
HC	0.091	0.45	4.50
NO_2	9.08	9.08	3.62
SO_2	$16.0 \times S^{(1)}$		

Note:　(1) the sulphur content

表4-4　　各种锅炉的污染物排放系数

Table 4-4　Pollutants Emissions Factors of Different Type Fuel Boilers

设备种类 Appliances		单位 Unit	燃料 Fuel	SOx	NOx	CO
锅炉 Boilers	发电用 For Power Generation	kg/kt	柴油 Diesel	—	6.63	0.005
		kg/kt	柴油与煤混烧 Diesel and Coal Mixed	—	5.53	0.005
		kg/t	天然气 Natural Gas	—	7.00	0.0087
焚烧炉 Incinerator	处理能力>300 吨/天 Capacity: > 300 t/d	kg/t	城市生活垃圾 Municipal Solid Waste	0.475 0.63	0.99	0.585
	处理能力 100-250 吨/天 Capacity: 100-250 t/d	kg/t		0.395 0.450	1.00	7.65
	处理能力>10 吨/天 Capacity: > 10 t/d	kg/t		Neg	1.50	35.5
熔炉 Melting Oven	平炉 Open-heart Furnace	kg/t	柴油 Diesel	17.6S	11.5	2.55
	化铁炉 Iron Melting	kg/t	焦炭 Coke	20.0S	1.10	30.0
	化铅炉 Lead Melting	kg/t	焦炭 Coke	8.0S	1.20	27.5
	反射炉 Reverberatory Furnace	kg/t	柴油 Diesel	17.6S	1.00	34.5
	金属加热炉 Metal Heating	kg/t	柴油 Diesel	17.6S	4.40	0.185
窑炉 Kiln	油炉 Oil Pit	kg/t	柴油 Diesel	17.6S	15.0	3.30
	坩埚 Crucible	kg/t	柴油 Diesel	17.6S	3.20	2.90

表4-5　　各种燃料燃烧时的污染物排放系数

Table 4-5　Pollutants Emissions Factors of Different Type Fuels

燃料	Fuel	单位 Unit	NO_2	SO_2	烟尘
煤	Coal	kg/t	9.00	17S	8A(1-E)
油	Oil	kg/L	2.85	4.2S	0.29(1-E)
天然气	Natural Gas	kg/10k m^3	6.30	1.00	2.40
煤	Coal	kg/M kcal	1.44	2.74S	1.22A(1-E)
油	Oil	kg/M kcal	1.24	1.89S	0.13(1-E)
天然气	Natural Gas	kg/M kcal	0.67	0.01	0.025

Note：S: sulphur content；A: dust content, %；E: combustion efficiency。

表4-6　　天然气燃烧设备的污染物排放系数单位：$g/1000m^3$

Table 4-6　Pollutants Emissions Factors of Natural Gas Boilers Unit: $g/1000m^3$

	电厂 Power Plant	工业锅炉 Industrial Boilers	民用取暖设备 Residential Heating Appliances
PM(1)	80-240	80-240	80-240
Sox	9.6	9.6	9.6
CO	272	272	320
HC(以CH4计)	16	48	128
NO_2	11200(2)	1920-3680(3)	1280-1290(4)

Note：(1) 天然气平均含硫量按 4.6 $g/10^3m^3$ 计；4.6 $g/10^3m^3$ sulfur natural gas;

(2) 对切向燃烧设备用 4800 $kg/10^6m^3$。当负荷降低时要乘负荷降低系数。即负荷为 40%时负荷降低系数取 0.35，负荷为 60%时取 0.46，负荷为 80%时取 0.66。

(3) 指一般工业锅炉，如大型工业锅炉，其产热量大于 104.67×10^6kJ/h，NO_2 排放量按电厂计;

(4) 家用取暖设备按 1280 取，民用取暖设备按 1290 取。

表4-7　　典型燃气锅炉的污染物排放系数

Table 4-7　Pollutants Emissions Factors of Typical Natural Gas Boilers

	公用或大型工业锅炉 Public Utility or Large Industry Boilers	商业或工业锅炉 Commercial or Industry Boilers			小型商业或民用锅炉 Small Scale Commercial or Residential Boilers		
	天然气 Natural Gas	天然气 Natural Gas	丁烷液化气 Butane	丙烷液化气 Propane	天然气 Natural Gas	丁烷液化气 Butane	丙烷液化气 Propane
Smoke	80-240	80-240	0.22	0.2	80-240	0.23	0.22
SOx	20.9	20.9	0.01	0.01	20.9	0.01	0.01
CO	272	272	0.19	0.18	320	0.24	0.23
CmHn	16	48	0.036	0.036	128	0.096	0.084
NOx	11200(1)	1920-3680	1.45	1.35	1280-1920(2)	1.0-1.5(2)	0.8-1.3(2)

注：　1. 污染物发生量单位为 $g/1000m^3$（天然气）或 g/L（液化石油气）。

2. 表中 SO_2 数值还需乘以 g 硫/$100Nm^3$（天然气）或 g 硫/$100Nm^3$（液化石油气蒸汽）。

(1) 表示 NO_2 数值需乘以 0.151exp(-0.0189L)，其中 L 为锅炉负荷百分数。对切向燃烧锅炉取 $4800g/1000m^3$。

(2) 低值为民用锅炉，高值为商业用采暖系统。

表4-8　　燃油锅炉污染物排放系数　　单位：g/L

Table 4-8　Pollutants Emissions Factors of Oil Boilers　　Unit: g/L

	锅炉类型，Boiler Type①			
	电厂, Power Plt	工业与民用, Ind. & Residential		家用精制油 Household Fine Oil
	渣油, Residual Oil	渣油, Residual Oil	精制油, Fine Oil	
PM	②	②	0.25	0.31
SO_2 ③	19S	19S	17S	17S
CO ④	0.63	0.63	0.63	0.63
HC(以CH4计) ⑤	0.12	0.12	0.12	0.12
NO_2	12.6(6.25) ⑥	7.5 ⑦	2.8	2.3

① 锅炉按产热量分类：电厂（公用事业）> 264×10^6kJ/h，工业锅炉 15.5~264×10^6kJ/h，民用锅炉 0.55~15.5×10^6kJ/h，家用锅炉 ＜0.55×10^6kJ/h。

② 燃烧渣油，颗粒物平均排放量取决于油的等级及含硫量，可按下式计算

6 号油：1.25（S）+0.38kg/kL，S 为油中含硫量，以百分数计；

5 号油：1.25 kg/kL；

4 号油：0.88 kg/kL。

③ S 为油中含硫量，以百分数计。

④ 如运转维护不好，CO 可增加 10~100 倍。

⑤ 通常 HC 排放量极少，只是在运转和维护不正常时其排放量才会大量增加。

⑥ 当满负荷、过剩空气量正常（> 15%）时，切向燃烧锅炉 6.25 kg/kL，其它锅炉为 12.6 kg/kL。锅炉负荷每降低 1%，NO_2 排放量相应降低 0.5~1%。

⑦ 民用和家用锅炉燃烧渣油时，NO_2 排放量取决于燃料中的含氮量，可用下列公式计算：

2.75+50（N）^{2} $kgNO_2/kL$

N 为油中含氮量，以质量百分值计。

当渣油含氮量高于 0.5%时，其排放量可按 15 $kgNO_2/kL$ 计算。

表4-9　　典型燃油锅炉污染物排放系数　　单位：g/L

Table 4-9　Pollutants Emissions Factors of Typical Oil Boilers　Unit: g/L

	公用或大型工业锅炉 Public Utility or Large Industry Boilers	商业或工业锅炉 Commercial or Industry Boilers		小型商业或民用锅炉 Small Scale Commercial or Residential Boilers
	重油 Heavy Oil	重油 Heavy Oil	重柴油 Heavy Diesel	重柴油 Heavy Diesel
Smoke	1.0	2.75	1.8	1.2
SO_2	19.2S	19.2S	17.2S	17.2S
CO	0.4	0.5	0.5	0.6
CmHn	0.25	0.35	0.35	0.35
Nox	12.6	9.6	9.6	1.5

注：　(1) 对切向燃油锅炉，NOx 发生量取表中数值的一半。

(2) S 为燃料含硫量。原油 0.1~3.3%，汽油<0.25%，轻油 0.5~0.75%，重油 0.5~3.5%。

表4-10　　钢铁工业不同工序吨产品污染物排放系数

Table 4-10　Pollutants Emissions Factors of Iron and Steel Process per ton Products

<table>
<tr><th>产品工序</th><th></th><th colspan="2">总量(Nm^3)</th><th>Dust</th><th>CO</th><th>SO_2</th><th>HC</th><th>NOx</th></tr>
<tr><td>焦炭</td><td></td><td colspan="2"></td><td>1.4-5 kg</td><td>0.33 kg</td><td>0.021 kg</td><td>0.16 kg</td><td>0.37 kg</td></tr>
<tr><td>洗精煤烧结</td><td></td><td colspan="2">4000-6000</td><td></td><td></td><td>0.5-1.5 g/ m^3</td><td></td><td></td></tr>
<tr><td rowspan="2">高炉生铁</td><td>高炉</td><td rowspan="2">1600-4500</td><td>2000-2500</td><td></td><td rowspan="2">20-30 %</td><td></td><td></td><td></td></tr>
<tr><td>出铁场</td><td>24.3 kg</td><td></td><td></td><td></td><td></td></tr>
<tr><td>吹氧转炉炼钢</td><td></td><td colspan="2">60</td><td></td><td>70-80 %</td><td>0.5 ppm</td><td></td><td>5 ppm</td></tr>
<tr><td>转炉兑铁水</td><td></td><td colspan="2">1.000-1.5 k Nm^3/t 铁水.h</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>转炉出钢</td><td></td><td colspan="2">0.8-10 k Nm^3/t 钢.h</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>电炉炼钢</td><td>不吹氧时</td><td colspan="2">400-600</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>吹氧时</td><td colspan="2">900-1500</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>平炉炼钢</td><td>吹氧时</td><td colspan="2">2000-3000</td><td></td><td>0.2-0.7 %</td><td></td><td></td><td></td></tr>
<tr><td></td><td>不吹氧时</td><td colspan="2">1000-2000</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>冲天炉生铁铸造</td><td></td><td colspan="2">750-800</td><td></td><td>17-19 %</td><td>0.10 %</td><td></td><td></td></tr>
<tr><td>硅铁合金</td><td></td><td colspan="2">10 k m^3</td><td>100-1500 kg</td><td></td><td>10 mg/m^3</td><td></td><td></td></tr>
<tr><td>钨铁合金</td><td></td><td colspan="2">60 k m^3</td><td>560mg/ Nm^3 或20-25 kg</td><td></td><td>170 mg/Nm^3</td><td></td><td></td></tr>
<tr><td rowspan="2">锰铁合金</td><td>封闭式电炉</td><td colspan="2">780-940</td><td>粉尘50-150 g/ Nm^3</td><td>73 %</td><td></td><td></td><td></td></tr>
<tr><td>敞口式电炉 9000 kVA</td><td colspan="2">88-119 kNm^3/h</td><td>4.13 g/ Nm^3 粉尘50-125 kg</td><td></td><td></td><td></td><td></td></tr>
<tr><td>硅锰铁</td><td></td><td colspan="2"></td><td>100 kg</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">钼铁</td><td>焙烧炉</td><td colspan="2">20 kNm^3/炉料.h</td><td>2-2.5 g/Nm^3</td><td>1.7 %</td><td></td><td></td><td></td></tr>
<tr><td>熔炼炉</td><td colspan="2">3 kNm^3/炉料.h</td><td>28 g/Nm^3</td><td>5 %</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">钒铁合金</td><td>封闭式电炉</td><td colspan="2">0.5-1.0 kNm^3</td><td>30-120 g/Nm^3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>敞开式电炉</td><td colspan="2">120-150 kNm^3</td><td>1-5 g/Nm^3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>回转炉</td><td colspan="2">60-80 kNm^3</td><td>0.5-0.8 t</td><td></td><td>1.8 g/Nm^3</td><td></td><td></td></tr>
<tr><td rowspan="3">炼钢混铁炉</td><td>130 t混铁炉</td><td colspan="2">200-300 kNm^3/h</td><td rowspan="3">1 g/Nm^3</td><td rowspan="3">0.4-0.8 %</td><td></td><td></td><td></td></tr>
<tr><td>600 t/炉</td><td colspan="2">150-200 kNm^3/h</td><td></td><td></td><td></td></tr>
<tr><td>300 t/炉</td><td colspan="2">80-100 kNm^3/h</td><td></td><td></td><td></td></tr>
</table>

4.3 The Pollutant Emission of Different Energy Consuming Sectors in Shanghai

4.3.1　SO_2 Emission

Shanghai energy balance and SO_2 emission calculating results of each energy-consuming sector indicate that SO_2 emission of Whole City in 1998 is 507,000 tons. In which, SO_2 emission of power plants is 319,000 tons, heating production system 282,000 tons, industry 134,000 tons, tertiary industry 27,300 tons and residential energy consumption 25,200 tons.

According to the contribution of SO_2 emission, SO_2 emission of secondary energy processing transfer occupies 63 percent of whole city, in which, power plant occupies 56 percent, heating production system 6 percent. SO_2 emission of end energy occupies 37 percent, in which , industry 26 percent, tertiary industry 5 percent, residential consumption 5 percent, agriculture 0.3 percent. Power plant and industry sectors are still the major SO_2 emission sources.

表4-11　　1995~1998 年上海市各用能部门 SO_2 排放量 单位：万吨

Table 4-11　SO_2 Emissions of Different Energy Sectors, 1995~1998　Unit: 10kt

用能部门	Sectors	1995	1998
1. 加工转换纯投入	1. Processing Transfer Input	32.7	31.9
1.1 火力发电	1.1 Power Generation	28.2	28.2
1.2 供热	1.2 Heat Production	4.01	3.15
1.3 炼焦	1.3 Coke Making	0.00	0.00
1.4 炼油	1.4 Oil Refining	0.00	0.00
1.5 制气	1.5 Gas Making	0.53	0.52
2. 终端消费量	2. End use	17.4	18.8
2.1 第一产业	2.1 Primary Industry	0.01	0.14
2.2 第二产业	2.2 Secondary Industry	12.4	13.4
2.3 第三产业	2.3 Tertiary Industry	2.25	2.73
2.4 生活消费	2.4 Residential Consumption	2.68	2.52
合计	Total	50.0	50.7

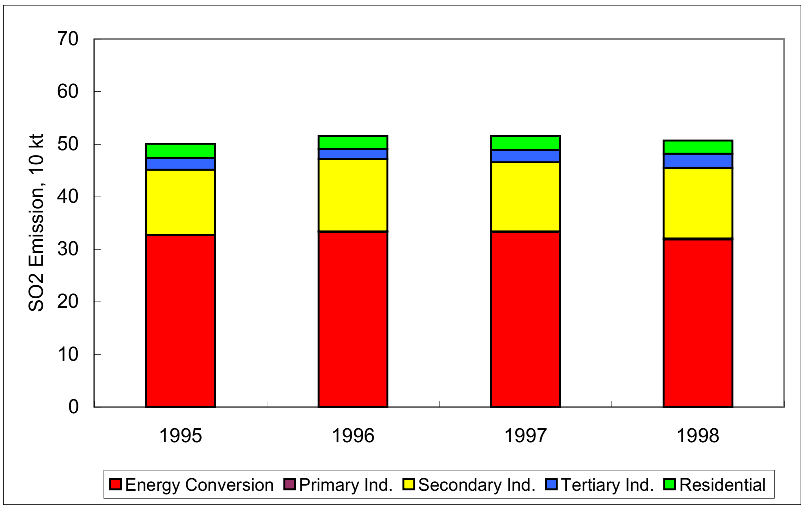

图4-1　　1995~1998 年上海市 SO_2 排放分担

Figure 4-1　Shanghai SO_2 Emission Contribution of Different Sources, 1995~1998

4.3.2　NOx Emission

NO_x emission calculating results of different energy consuming sectors in whole city indicates that

NO_x emission of whole city in 1998 is 400,000 tons. In which, NO_x emission of power plant is 170,000 tons, that of heating production system, coke making and gas making, industry emission, tertiary industry, residential consumption emission, road transportation and non road transportation (includes train, steamship and airplane) is 18,000 tons, 2600 tons, 94,000 tons, 3,000 tons, 8,000 tons, 82,100 tons and 15,200 tons, respectively.

Seen from NO_x emission increasing condition, NO_x emission of secondary energy processing transfer occupies 48% of whole city. In which, power plant occupies 43 %, heating production system 4.4%, coking and gas making 0.7%. NOx emission of end energy occupies 27%, in which, industry 24%, tertiary industry 0.8%, residential consumption emission 2%, agriculture 0.8% and construction 0.8%. NOx emission of transportation occupies 24.5%, in which, motor vehicle emission 21%, non-road transportation 4%.

表4-12　　1995~1998 年上海市各用能部门 NOx 排放量　　单位：万吨

Table 4-12　NOx Emissions of Different Energy Sectors, 1995~1998　Unit: 10kt

用能部门	Sectors	1995	1998
1. 加工转换纯投入	1. Processing Transfer Input	16.87	19.13
1.1 火力发电	1.1 Power Generation	14.54	17.11
1.2 供热	1.2 Heat Production	2.09	1.76
1.3 炼焦	1.3 Coke Making	0.22	0.24
1.4 炼油	1.4 Oil Refining	0.00	0.00
1.5 制气	1.5 Gas Making	0.02	0.02
2. 终端消费量	2. End use	9.90	10.79
2.1 第一产业	2.1 Primary Industry	0.00	0.03
2.2 第二产业	2.2 Secondary Industry	8.88	9.65
2.3 第三产业	2.3 Tertiary Industry	0.28	0.32
2.4 生活消费	2.4 Residential Consumption	0.74	0.78
3. 交通	3. Transportation	7.98	9.73
合计	Total	34.75	39.64

According to NOx emission increasing condition of whole city in 1995 - 1998, as a whole, NO_x emission of motor vehicle presents increasing trend. Major NO_x emission sources are power plant, industry and transportation.

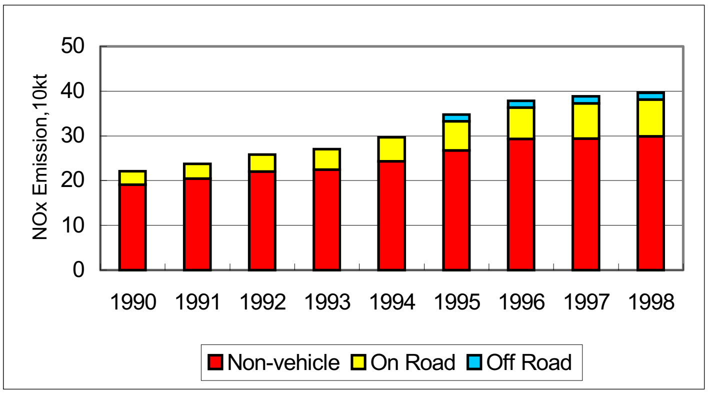

图4-2　　1990~1998 年上海市机动车与非机动车 NOx 排放量

Figure 4-2　Shanghai Mobile and Non-mobile NOx Emissions, 1990~1998

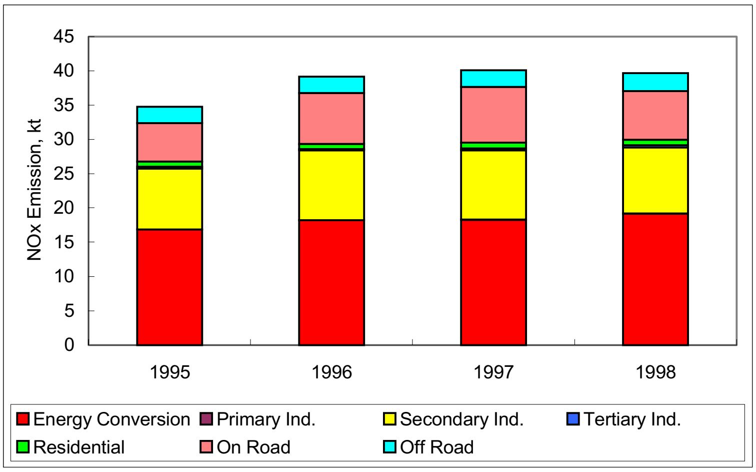

图4-3　　1995~1998 年上海市各种排放源的 NOx 排放分担

Figure 4-3　Shanghai NOx Emissions from Different Sources, 1995~1998

4.3.3　CO_2 Emission

(1) Calculate Methods

Adopting three different methods to calculate CO_2 emission.

- The first method is simple numeration, the result gets by CO_2 emission per ton of standard coal multiply Shanghai macroscopical energy consumption. The method is simple and is popularly used to verify complicated calculate results. The formula is below:

  CO_2 emission（t CO_2）=EF（t CO_2 / t SCE）×Shanghai energy consumption（t SCE）

  EF is CO_2 emission factors.

- The second is inverse calculation method. Adopting DOE/EIA CO_2 emission of various mineral fuel used in China in 1980~1998, calculating by actual consumption of various mineral fuel in Shanghai and corresponding energy consumption in China. For example, if coal consumption in China is A (t SCE) and its corresponding CO_2 emission is B(t CO_2), Shanghai's coal consumption is a (t SCE), CO_2 emission (t CO_2) from coal burning can be showed as below formula:

  Shanghai CO_2 emission from coal burning = National CO_2 emission from coal burning B (t CO_2)/ National coal consumption A (t SCE) ×Shanghai coal consumption a (t SCE)

The precondition of the method is that national CO_2 emission must be known.

- The third is factor input calculation method. According to energy type, energy appliances, CO_2 emission of consumption unit PJ energy and given emission factors, calculate CO_2 emission.

CO_2 emission = CO_2 emission factor(Mt/PJ) ×energy consumption (PJ)

The precondition of the method is that various mineral energy, CO_2 emission factor of energy appliances, energy consumption and energy type must be mastered. CO_2 emission factor adopted by this study is from MARKAL model, energy consumption of every appliance is from Shanghai energy balance table in 1995 ~1998. The referenced CO_2 emission factors are listed in Table 4-13.

表4-13　　各种能源 CO_2 排放系数　单位：Mt/PJ

Table 4-13　CO_2 Emission Factors of Different Energy Carries,　Unit: Mt/PJ

能源品种	Energy Carries	CO_2排放系数
原煤	Coal	0.094
洗精煤	Coking Coal	0.094
焦炭	Coke	0.11
焦炉煤气	Coal Gas	0.12
其它煤气	Other Gas	0.12
原油	Crude Oil	0.073-0.075
汽油	Gasoline	0.056
煤油	Kerosene	0.073
柴油	Diesel	0.073
燃料油	Fuel Oil	0.073
液化石油气	LGP	0.073

(2) CO_2 emission

The calculating result indicates that Shanghai CO_2 emission calculated by different methods has a little difference. As a whole, CO_2 emission increases year after year. CO_2 emission contribution from coals burning down 66 percent in 1998 from 79 percent in 1980. Oil consumption emission contribution up 34 percent in 1998 from 21 percent in 1980.

CO_2 emission in 1998 year is 12.4 million to 13.2 million tons. In which, power plant occupies 29~31 percent, heating production system 3~4 percent, coke making 1~2percent, gas making 1 percent, oil refining 10 percent, agriculture 1 percent, industry 45 percent, tertiary industry 6-9 percent, residential consumption 5-6 percent.

表4-14　　不同计算方法得到的全市 CO_2 排放量　单位：亿吨

Table 4-14　CO_2 Emission by Different Calculations,　Unit: 100Mt

	简易计算法	反推计算法	参数输入计算法
1995	1.18	1.16	1.19
1998	1.26	1.24	1.32

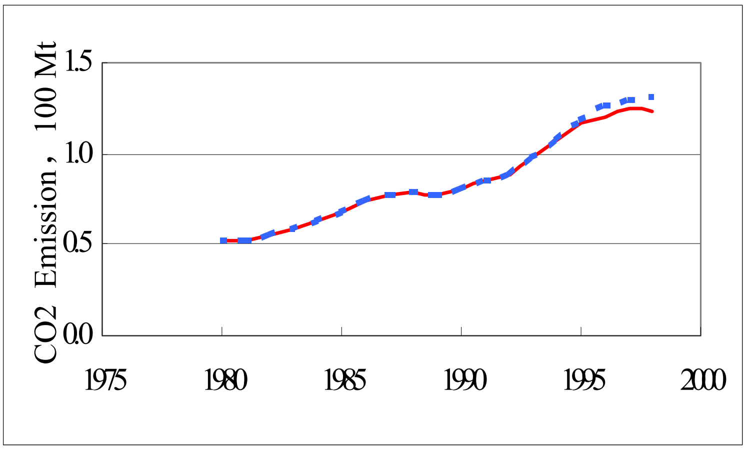

图4-4　　1980~1998 年上海市 CO_2 排放量

Figure 4-4　Shanghai CO_2 Emission, 1980~1998

表4-15 上海市各种用能部门 CO_2 排放量 单位：100Mt

Table 4-15 CO_2 Emission of Different Sectors, Unit: 100Mt

用能部门	Sectors	1995	1998
一、加工转换投入(-)，产出(+)量	1. Processing Transfer Input	-0.48	-0.58
火力发电	1.1 Power Generation	-0.35	-0.41
供热	1.2 Heat Production	-0.05	-0.04
炼焦	1.3 Coke Making	0.02	0.02
炼油	1.4 Oil Refining	-0.12	-0.14
制气	1.5 Gas Making	0.01	0.00
二、损失量	2. Loss Volume	0.01	0.02
三、终端消费量	3. End use	0.68	0.72
第一产业	3.1 Primary Industry	0.01	0.01
第二产业	3.2 Secondary Industry	0.54	0.51
第三产业	3.3 Tertiary Industry	0.08	0.12
生活消费	3.4 Residential Consumption	0.06	0.08
四、平衡差额	4. Balance	0.00	0.01
五、合计	5. Total	1.19	1.32

表4-16 上海市各种用能部门 CO_2 排放分担率 单位：%

Table 4-16 CO_2 Emission of Different Sectors, Unit: %

本研究计算 Results produced by this study			MARKAL模型计算结果 Results produced by MARKAL	
电厂	Power Plants	29.3	电厂	27.9
供热	Heat Production	3.9		
炼焦制气	Coke and Gas Production	2.2		
炼油	Oil Refinery	9.7		
工业	Industry	44.9	工业	60.0
交通	Transportation	4.0	交通	4.2
生活	Residential	5.0	生活	4.9
仓储	Bunkers			3.0
其它	Others	1.0		
合计	Total	100		100

4.4 Summary

CO_2 and pollutant emission calculation results indicate:

(1) In recent years, Shanghai strictly controls the sulphur quantity of fuel. Although energy consumption increases year after year, SO_2 emission does not increase. Shanghai SO_2 emission is about 580,000 tons in 1998, lower than that of 1996 and 1997. SO_2 emission of power plant accounts for 50 percent of total SO_2 emission, other second energy processing transfer sectors

occupies 8 percent, industry 27 percent, tertiary industry 7 percent, residential use 6 percent.

(2) NOx_x emission in Shanghai increases quickly, the coal burning pollution control measures does not effectively control NOx_x emission pollution. Shanghai total NOx_x emission is about 400,000 tons in 1998 , up 9 percent, 12 percent and 14 percent over 1995, 1996 and 1997, respectively. NOx_x emission of power plant accounts for 50 percent of total NOx_x emission, other second energy processing transfer sectors occupies 5 percent, industry 24 percent, road transportation 21 percent, non-road transportation 4 percent, residential use 2 percent.

(3) According to this study, Shanghai CO_2 emission from mineral fuel burning is in an increasing stage. CO_2 emission of each year is more than 100,000,000 tons since 1994. It reached 130,000,000 tons in 1998. In which, power plant accounted for 29 percent, other secondary energy processing transfer sectors 16 percent, industry 45 percent, transportation 4 percent, residential use 6 percent, other sources 1 percent.

5. Historical Energy and Environmental Policy and Its Environmental Benefit

5.1. Policies Implemented

5.1.1 Energy Supply & Consumption Polices

During 1980’s to1990’s, energy consumption was dramatically increased in line with a high economic growth, causing scarcity in energy and power supply. Coal contributed 75% of the primary energy consumption, which caused unbalanced energy consumption and serious air pollution of SO_2, smoke and dust from coal-burning.

To improve the air quality, a new concept of coordinated development of energy and environment was put forward in 1995. It was aimed at reducing air pollution from coal-burning with improving energy supply and consumption, e.g. reduction of coal-consumption, balanced use of energy, improvement of energy efficiency, etc.

Thanks to this policy, burden of energy supply has been alleviated since 1996 and proportion of coal in the primary energy supply was reduced. However, total amount of coal consumption was still increased, and SO_2 emission reached to 510,000 ton/a. Therefore, in 1996 strategy of sustainable energy development was put forward. Meanwhile, more measures was taken, such as exploration of natural gas from East China Sea Oil Field, replacement of coal-burning boilers with cleaner fuels, development of clean energy and renewable energy, and using electricity from other provinces, etc.

To improve energy efficiency, a local regulation on energy-saving was issued in 1997 to promote the sustainable development of energy and environment. In this year, natural gas project from East China Sea was formally started.

In 1998, an action plan on sustainable development of energy and environment was prepared. Policies on balanced use of energy, development of renewable energy, and improvement of energy planning and management were listed as three major ones for the sustainable development of energy, environment and society of Shanghai.

5.1.2 Environment Policies

Controlling air pollution has been started since 1970’s in Shanghai. In 1980’s, policy “Polluter should be responsible for treatment” was put forward, which was aimed at reducing coal-burning pollution and setup “no black smoke zone” in Shanghai. Three industrial sectors, power plant, metallurgy and cement were regarded as major pollution sources. During 1980’s, a series of local regulations on smoke and dust control in Shanghai (1988), pollution fee collection and fines (1984), policies on improving management on pollution treatment facilities (1989) and standard on industrial emissions were issued.

With using of some dust-removal facilities, popularization of town-gas and district heating, industrial dust from kilns, power plants and metallurgical industries were reduced.

Since mid 1980’s, domestic balanced use of energies has been improved, meanwhile, major tasks for industrial pollution control were shifted from black-smoke control to smoke-and-dust control. Rehabilitation of some heavy-polluted areas like Hetian Road, Xinhua Road, and Taopu industrial areas were listed as top agenda.

Since 1990's, with restructuring of urban layout and industrial sectors, air pollution control in Shanghai was shifted from previous point-source focused to rehabilitation of heavy-polluted areas, meanwhile, rehabilitation of urban environment was strengthened, and target for total load control of SO_2 was put forward.

In late 1990's, based on the national planning of controlling acid rain and SO_2, a strategy of setting up "no coal-burning area" was put forward in Shanghai. Measures on sustainable development of energy and environment, and cleaner production have been implemented. Pollution control have been gradually shifted from end-of-pipe treatment to whole-process control. Coal-burning as well as petrol-combustion have been paid attention to. Strategies of pollution control have been focused on regional pollution control, comprehensive rehabilitation of urban.

5.2. Energy Structure and Elasticity Coefficient of Energy Consumption

According to statistics conducted by Shanghai Planning Commission, ratio of coal consumption has been maintained at 70% in Shanghai（fig 5-1）。Elasticity coefficient of energy consumption was reduced from 0.48 in 1995 to 0.24 in 1998.（fig 5-2）. And popularization of town-gas was increased from 86.6% in 1995 to over 95% in 1998 (fig 5-3).

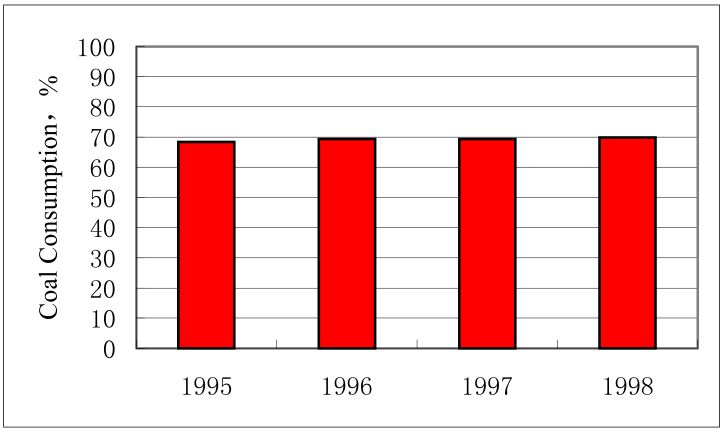

图5-1　1995~1998 年全市煤炭在一次能源消费中的比重

Figture 5-1　　Coal Consumption Ratio, 1995~1998

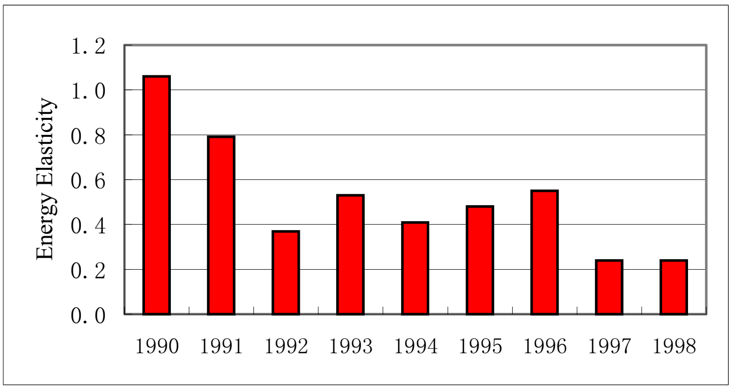

图5-2　1990~1998 年全市能源消费弹性系数

Figture 5-2　　Elasticity Coefficient of Shanghai Energy Consumption, 1990~1998

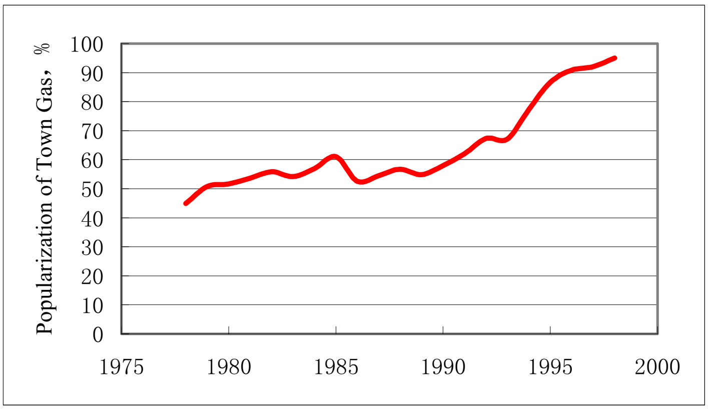

图5-3 1980~1998 年全市煤气普及率

Figture 5-3 Household Popularization of Town Gas Consumption, 1980~1998

5.3. Energy Consumption per unit GDP for Different Industries in Shanghai

The statistics of energy consumption per unit GDP for different industries for year 1990 to 1998 illustrated the declining of energy consumption due to effective implementation of policies on energy and environment.

Based on price of 1990, energy consumption per unit GDP was reduced from 3.21 ton of standard coal in 1995 to 2.51 ton in 1998(fig 5-4).

In 1998, energy consumption for each industry was 907,300 ton, 268.525 million tons and 5.4783 million ton of standard coal respectively. And energy consumption for per unit GDP for each industry was 1.16 ton, 1.45 ton and 0.83 ton of standard coal respectively.

Energy consumption per unit GDP in 1998 for each industry was 26%, 64% and 70% lower than that of 1990 respectively.

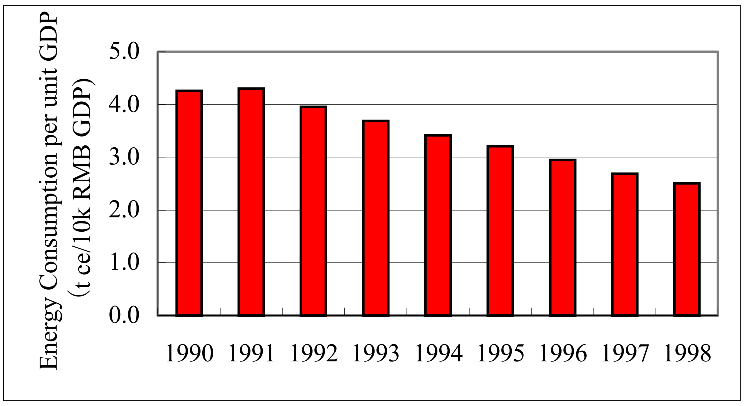

图5-4 1990~1998 年全市万元 GDP 能源消费量(90 年价格)

Figture 5-4 Energy Consumption per unit GDP, 1990~1998 (90's Price)

表5-1　　1990~1998 年上海市物质生产部门万元 GDP 相对能耗（1990=100）

Table 5-1　Relative Energy Consumption per unit GDP by Sectors, 1990~1998（1990=100）

年份 Year	第一产业 Primary Ind.	第二产业 2nd Ind.	工业 Industry	建筑业 Construction	第三产业 3rd Ind.	交通仓储 Trans. & Storage	零售批发 Whole Sale & Retailer
1990	100	100	100	100	100	100	100
1991	94	96	96	88	83	82	80
1992	99	85	84	123	67	76	46
1993	70	66	66	51	43	56	25
1994	61	50	50	64	33	43	26
1995	80	45	45	47	31	37	46
1996	93	40	41	42	29	40	27
1997	77	37	38	44	29	41	25
1998	74	36	36	43	30	43	27

5.4.　SO_2 and Dust Emission

Since 1995, the total SO_2 emission of Shanghai was controlled below 500,000 ton/a (fig 5-5), and emission of smoke and dust has been declined annually (fig 5-6).

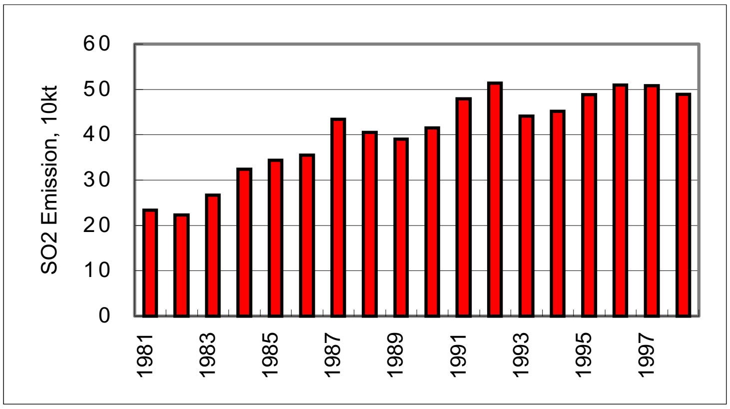

图5-5　1981~1998 年全市 SO_2 排放量

Figture 5-5　　Shanghai SO_2 emission, 1981~1998

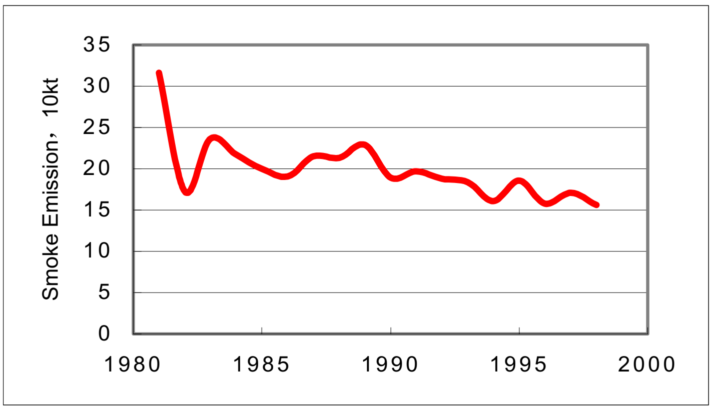

图5-6　1981~1998 年全市燃煤烟尘排放量

Figture 5-6　　Shanghai Smoke emission from Coal Burning, 1981~1998

5.5. Ambient Air Quality

5.5.1 SO_2 Pollution

Over the past several years, yearly concentration of SO_2 has been reduced in Shanghai through pollution control over fuel pollutant content and coal-burning. The yearly concentration of SO_2 of Shanghai in 1998 was 0.025mg/m^3，11% lower than that of 1995，and only 0.5% samples failed to meet with daily concentration standard of SO_2. The yearly concentration of SO_2 in the downtown area was 0.52 mg/m^3，a little bit lower than that of 1995, and 1.3% samples failed to meet with the daily concentration standard. Regards the daily concentration of SO_2, for whole Shanghai it was 59% lower in 1998 than that of 1986, and for downtown area it was 61% lower. Concentration of SO_2 has been in compliance with Class II of national standard for whole city, while it meets with Class I standard in the rural area.

表5-2　　1986~1998 年上海市 SO_2 年日平均浓度变化

Table 5-2　Yearly Concentration of SO_2, 1986~1998(1986=100)

年份 Year	全市 City-wide	城区 Urban Area
1986	100	100
1987	89	79
1988	87	78
1989	84	73
1990	79	71
1991	100	80
1992	95	70
1993	87	68
1994	62	56
1995	52	40
1996	52	44
1997	52	51
1998	41	39

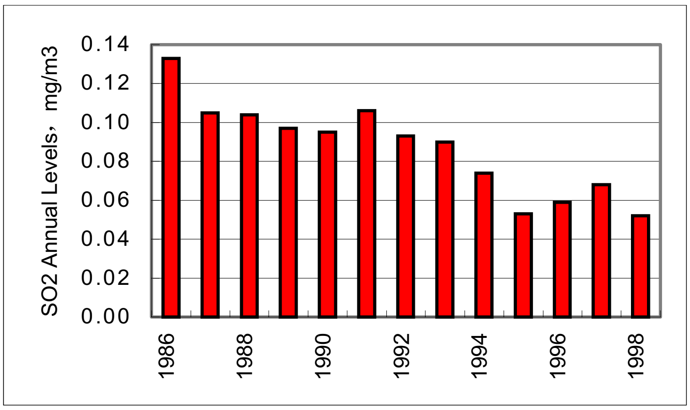

图5-7　1986~1998 年上海市城区 SO_2 浓度

Figure 5-7　　SO_2 Concentration in Shanghai Urban Area, 1986~1998

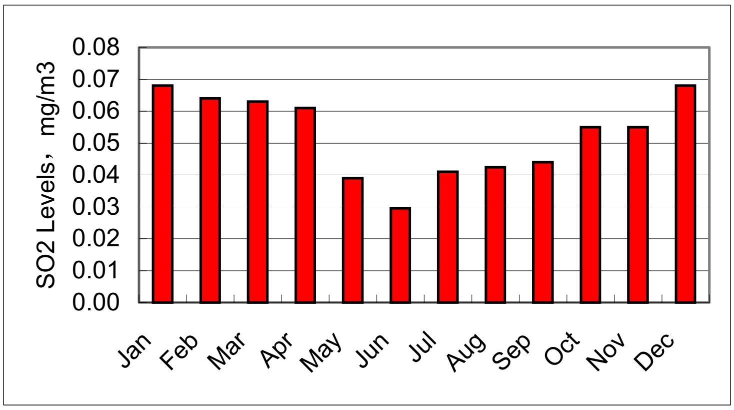

图5-8　1998 年上海市城区 SO_2 各月平均浓度

Figture 5-8　Monthly Average of SO_2 Concentration in Shanghai Urban Area, 1998

5.5.2 NOx Pollution

However, policies and measures for energy and environment mainly focus on coal-burning pollution, and in terms of NOx pollution they are ineffective. Daily concentration of NOx in the downtown area from 1986 to 1998 shows the deterioration of NOx pollution since 1995 from 0.07 mg/m^3.

Daily concentration of NOx of downtown area in 1998 is 0.10 mg/m^3, meeting with Class III of national standard. It was 0.028 mg/m^3 higher than that of 1995, and 38% samples failed to meet with the daily concentration standard. For whole Shanghai, the daily concentration NOx in 1998 was 35% higher than that of 1986, and for downtown area, it was 54% higher.

表5-3　1986~1998 年上海市 NOx 年日平均浓度变化

Table 5-3　Annual Average of NOx, 1986~1998(1986=100)

年份 Year	全市 City-wide	城区 Urban Area
1986	100	100
1987	95	95
1988	100	103
1989	95	97
1990	93	95
1991	107	102
1992	133	129
1993	114	115
1994	98	92
1995	116	111
1996	126	137
1997	137	162
1998	135	154

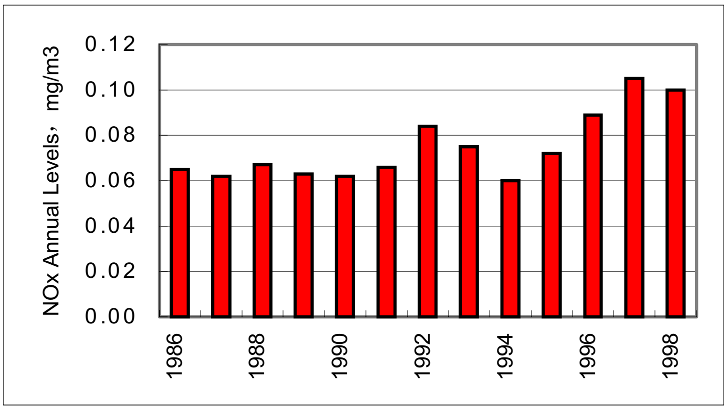

图5-9 1986~1998 年上海市城区 NOx 浓度

Figture 5-9 NOx Concentration in Shanghai Urban Area, 1986~1998

With the stabilization of NOx emission from industrial pollution sources and greatly increasing of vehicle population, motor vehicles have become a major contributor to NOx pollution since 1995.

5.5.3 TSP Pollution

It can be illustrated from figure 5-11 that with some effective environmental polices, such as popularization of town-gas, establishment of smoke control zone etc., concentration of TSP has been dramatically decreased.

Concentration of TSP of Shanghai in 1998 was 33% lower than that of 1990, and in the downtown area it was 40% lower. TSP concentration for the whole city can meet with Class II of national ambient air quality standard, while for the downtown area it is closing to the Class II standard. High TSP concentration mainly focuses in Luwan, Nanshi and Huangpu District. And concentration of TSP has an increasing tendency in the rural area.

表5-4 1990~1998 年上海市 TSP 年均浓度变化

Table 5-4 Yearly Concentration of TSP, 1990~1998(1990=100)

年份 Year	全市 City-wide	城区 Urban Area
1990	100	100
1991	92	92
1992	99	90
1993	87	79
1994	87	78
1995	83	69
1996	81	67
1997	75	65
1998	67	60

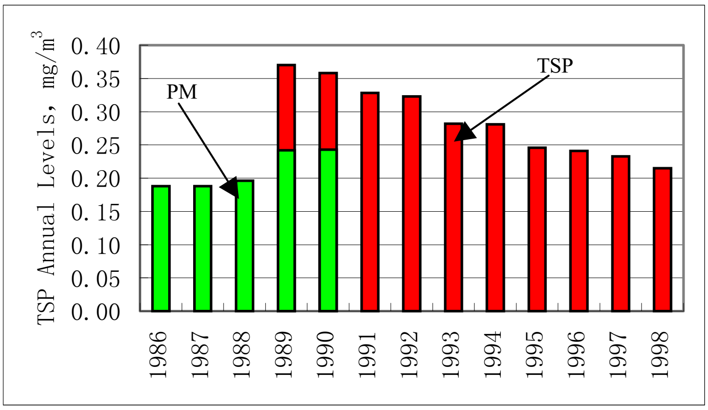

图5-10 1986~1998 年上海市城区 PM_{10} 和 TSP 浓度

Figture 5-10 PM_{10} and TSP Concentration in Shanghai Urban Area, 1986~1998

5.6. Conclusion

(1) With effective energy and environmental management, such as energy-saving, limiting the expanding of industries with high energy consumption and low-added value, total amount of coal consumption control, and improvement of end treatment, scarcity of energy supply has been preliminary alleviated;

(2) Even with a high economic growth, increasing of energy consumption in Shanghai is slowing down. Elasticity coefficient of energy consumption was declined from 1.0 in 1990 to 0.24 in 1998. Energy consumption per 10,000 GDP for primary, secondary and tertiary industry in 1998 was 26%, 64% and 70% lower than that of 1990 respectively;

(3) Coal-burning pollution has been under control. With improvement of balanced use of energy and control of coal-burning, coal consumption ratio has been maintained at 70%. Annual SO_2 emission in Shanghai is 500,000 ton;

(4) Reduction of coal-burning and improvement on emission treatment of medium-and-small-sized boilers have made great achievements. Concentration of SO_2 in the downtown area in 1998 was 55% lower than that of 1998, and TSP concentration was 40% lower; Motor vehicle becomes the major contributor of NOx pollution.;

(5) PM pollution is a potential threat to the ambient air quality in Shanghai. Studies on PM, particularly on PM_{10} are far from enough;

(6) Based on the strategy of coordinated development of energy and environment, energy and resource condition, environmental quality objectives and improvement of citizen's living standard, an overall planning on pollutant emission control target is needed to realize this strategy.

6. Future Energy Demand in Shanghai

6.1 Population

According to "21 Century Agenda for China - Shanghai Action Plan", the total citizens and residents in Shanghai would be at about 13.5 million and 15.5 million respectively in the year 2005, and 14 million and 16 million in the year 2010. The total population for the long term would be controlled under the ceiling of 17 million.

表6-1　上海市人口规模　单位：万人
Table 6-1　Future Population　Unit: 10 Thousand

年份 Year	户籍人口 Domicile population	常住人口 Permanent population
2005	1350	1450~1500
2010	1379	1479~1530
2020	1440	1540~1590

According to the urbanization progression in Shanghai, the population in urban area would be increased up to 13 million, the population in suburb would be reduced to 2 million, and the resident from other province would be at 1.0~1.5 million.

表6-2　上海市人口划分　单位：万人
Table 6-2　Future Population　Unit: 10 Thousand

年份 Year	常住人口 Permanent population	户籍人口，Domicile population		外地常住人口 Emigration
		城市人口 Urban Population	农村人口 Rural Population	
1990	1283.35	783.48	499.87	
1995	1301.37	956.66	344.71	
1998	1306.58	1070.62	235.96	
2005	1450~1500	1121	228	100~150
2010	1479~1530	1157	222	100~150
2020	1540~1590	1228	211	100~150

6.2 GDP Projection in Shanghai

6.2.1 Scenario Design for GDP Increment

In order to predict the energy consumption in Shanghai, GDP and GDP index for 1952~1998 was collected, and all the GDP was converted to 1995 price. Finally, GDP for 2005~2020 was predicted on the basis of GDP increment design.

The design of Shanghai GDP increment is detailed in Table 6-3.

表6-3　　2000~2020 年上海市 GDP 增长情景设计　　单位：%

Table 6-3　Design of Shanghai GDP Increment，2000~2020　　Unit: %

年份 Year	高方案 High Speed	中方案 Medium Speed	低方案 Low Speed
1990	3.5	3.5	3.5
1995	14.1	14.1	14.1
1998	10.1	10.1	10.1
2001-2005	11	10	9
2006-2010	9.5	8.5	7.5
2011-2020	8.5	7.5	6.5

6.2.2 Industry Structure

The industry structure in Shanghai would go towards “tertiary, secondary, primary ” direction, i.e. speed up the development of tertiary industry and high-tech industry, and increase its proportion in the industry structure, speed up the development of mainstay industry, develop the industry which consumes low energy and produces low pollution, seek after agriculture for city. The industry structure is detailed in Table 6-4.

表6-4　　上海市产业结构　　单位：%

Table 6-4　Shanghai Economic Structures　　Unit: %

产业	Industries	1995	2000	2005	2010
第一产业	Primary Ind.	2.4	2	1.5	1
第二产业	Secondary Ind.	57.5	48	43.5	39
第三产业	Tertiary Ind.	40.1	50	55	60

6.2.3 Projection for GDP Increment

According to the high, medium and low speed for GDP increment, GDP for year 2020 would reach at 1701~2575 billion Yuan on the base of 1995 price. GDP for year 2000~2020 is detailed in Table 6-5.

表6-5　　2000~2020 年上海市 GDP 增长情景　　单位：亿元

Table 6-5　Shanghai GDP Increment，2000~2020　Unit: 100 million RMB

年份 Year	高方案 High Speed	中方案 Medium Speed	低方案 Low Speed
1995	2463	2463	2463
2005	7233	6759	6312
2010	11387	10164	9062
2015	17122	14591	12415
2020	25746	20948	17010

According to the industry structure, GDP for the primary industry would go up to 17~15.8 billion by year 2020 from 6.2 billion in 1995, GDP for the secondary industry would go up to 663.4~1004.1 billion by year 2020 from 141 billion in 1995, GDP for the tertiary industry would go up to 1020.6~1544.7 billion by year 2020 from 99.1 billion in 1995. GDP for the primary, secondary and tertiary industry is detailed in Table 6-6 ~ Table 6-8 for 2000~2020.

表6-6　　2000~2020 年上海市各产业 GDP 增长情景（高方案）　　单位：亿元

Table 6-6　Shanghai Industrial GDP Increment (with higher speed)，2000~2020

Unit: 100 million RMB

年份 Year	第一产业 Primary Ind.	第二产业 Secondary Ind.	第三产业 Tertiary Ind.	全市 Total
1995	62	1410	991	2463
2005	110	3145	3978	7233
2010	147	4787	6453	11387
2015	195	6939	9988	17122
2020	258	10041	15447	25746

表6-7　　2000~2020 年上海市各产业 GDP 增长情景（中方案）　　单位：亿元

Table 6-7　Shanghai Industrial GDP Increment (with middle speed)，2000~2020

Unit: 100 million RMB

年份 Year	第一产业 Primary Ind.	第二产业 Secondary Ind.	第三产业 Tertiary Ind.	全市 Total
1995	62	1410	991	2463
2005	103	2938	3718	6759
2010	131	4274	5759	10164
2015	166	5913	8512	14591
2020	210	8169	12569	20948

表6-8　　2000~2020 年上海市各产业 GDP 增长情景（低方案）　　单位：亿元

Table 6-8　Shanghai Industrial GDP Increment (with lower speed)，2000~2020

Unit: 100 million RMB

年份 Year	第一产业 Primary Ind.	第二产业 Secondary Ind.	第三产业 Tertiary Ind.	全市 Total
1995	62	1410	991	2463
2005	96	2744	3472	6312
2010	117	3810	5135	9062
2015	142	5031	7242	12415
2020	170	6634	10206	17010

6.3 Energy Efficiency of Major Facilities

Major facilities which consume energy in Shanghai include boiler, motor, vehicle, aviation facility and electricity appliance etc.. According to the investigation in this study, the efficiency for major facilities is detailed in Table 6-9.

表6-9　　上海市主要用能设备的能源效率　　单位：%

Table 6-9　　Efficiency of Major Facilities　　Unit: %

设备	Facility	效率 Efficiency	设备	Facility	效率 Efficiency
锅炉	Boiler	63	水运	Marine Bunker	35
中小电机	Motors	87	热水器	Hot Water	36.2
电力机车	Elec. Motive	60	家用电器	Household Elec. Appliance	90
内燃机车	Internal Combustion Engine	30	炊事	Cooking	16.25
汽油车	Gasoline Vehicle	20	机械	Machinery	30
柴油车	Diesel Vehicle	30	其他	Others	40

6.4 Projection of Energy consumption for Living in Shanghai

6.4.1 Projection of Gas Consumption for Domestic Use

6.4.1.1Gas Consumption Per Person

Gas is mainly consumed for cooking, heat water supply and warming in domestic use in Shanghai. Gas consumption per person could be calculated as below:

$$energyforcookingperperson\left(\frac{tonSCE}{perperson}\right)=\frac{totalenergyconsumptionforcooking(10ktonSCE)}{populationu\sin nggas(10000)}$$

$$\begin{matrix} energyforwaterheater \\ andheatingfacilityperper \end{matrix}\left(\frac{tonSCE}{perperson}\right)=\frac{totaenergyconsumptionforheating(10ktonSEC)}{populationu\sin ggas(10000)}$$

According to the living energy statistic for 1990~1998, gas consumption for living use was 60.6 10kt CE 1998, i.e 88 kg CE per person (see Figure 6-2).

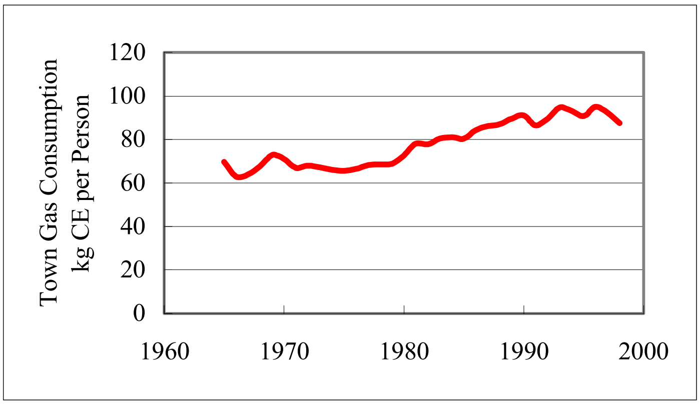

图 6-2 上海市人均煤气消费量

Figure 6-2 Average Town Gas Consumption per Person

According to the calculation, energy consumption for cooking per person various from 63 kg CE to 81 kg CE with the average of 70.1 kg CE (see Figure 6-3), energy consumption for heating facility and water heater per person various form 14.0 kg CE to 15.8 10kt CE with the average of 15.0 kg CE (see Figure 6-4).

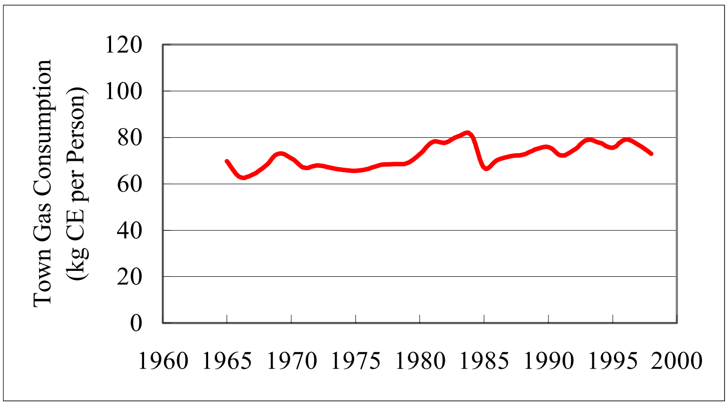

图 6-3　　　　上海市人均烹饪煤气消费量

Figure 6-3　　Average Town Gas Consumption for Cooking

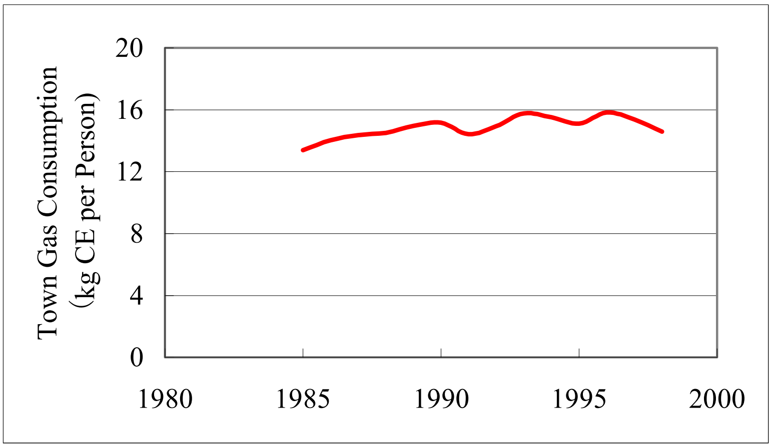

图 6-4　　　　上海市人均热水器和取暖器煤气消费量

Figure 6-4　　Average Town Gas Consumption for Hot Water

6.4.1.2 Projection of Gas Consumption for Living Use

According to the trends in 1990~1998, water heater becomes the absolutely necessary appliance in the living. With the improvement of living level, the possession of water heaters would reach 98 per 100 familiy.

表6-10　　1995~1998 年上海市城市居民热水器拥有量 单位：台/百户居民

Table 6-10　Possession of Hot Water Equipment of Residents, 1995~1998　Unit: Sets/100 Households

年份 Year	城市百户居民热水器拥有量 Possession of Hot Water Equipment	年份 Year	城市百户居民热水器拥有量 Possession of Hot Water Equipment
1995	37	2005	98
1996	42	2010	98
1997	51	2015	98
1998	60	2020	98

According to the increment of population and water heater possession in urban area and energy consumption for cooking and water heater per person, gas consumption would reach at 44 PJ in Shanghai by year 2020 of which 21.5 PJ for cooking and 22.3 PJ for water heater. Gas consumption for urban residents for year 2000~2020 is illustrated in Figure 6-5.

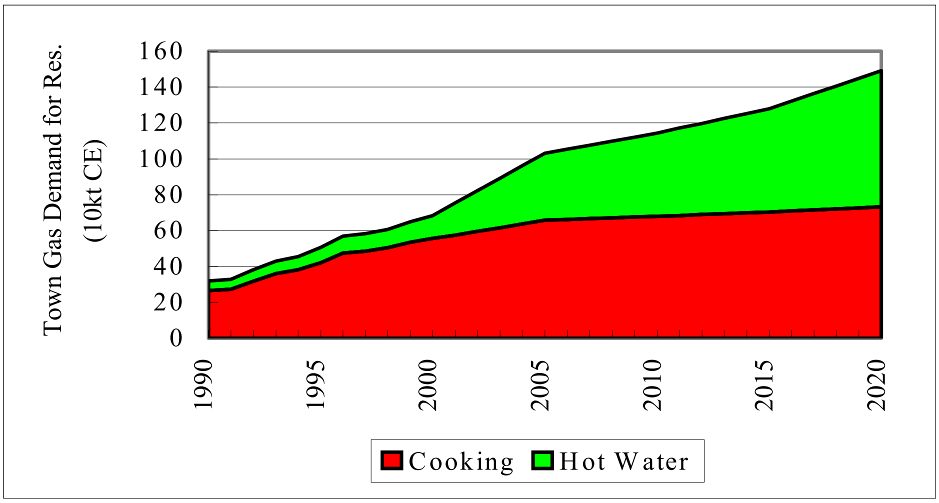

图 6-5　　2000~2020 年上海市城市居民煤气需求

Figure 6-5　　Coal Gas Demand of Urban Residents, 2000~2020

6.4.2 Projection of LPG Demand of Residents

6.4.2.1 LPG Consumption Per Person

People who using LPG maily live in the country and the suburb. As the living level in the country is relatively low in comparison with that in urban area, the water heater possession for 100 familiy is lower. The LPG is mainly used for cooking. LPG consumption per person was 53 kg CE in 1998, of which some 15 kg CE was consumed on water heater.

According to the statistic for 1980~1998, LPG consumption show a decrease trend because of the outgoing of labor force in the country (see Figure 6-6).

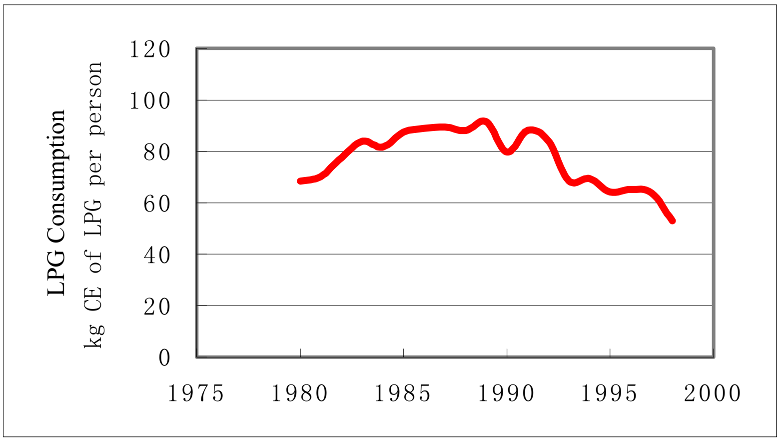

图 6-6　　上海市人均烹饪 LPG 年消费量

Figure 6-6　　Average LPG Consumption for Cooking

6.4.2.2 Projection of LPG Demand of Residents

People who using LPG mainly live in the country and the suburb. According to the statistic, the possession of water heater in country and the suburb area was 42.5 per 100 families and 29 per 100 families respectively in 1998, which is relatively lower in comparison with that in urban area. However, the possession of water heater either in the country or in the suburb would reach 98 per 100 families for year 2010 with the improvement of living level.

表6-11　2005~2020 年上海市城乡居民和农村居民热水器拥有量　单位：台/百户居民

Table 6-11　Possession of Hot Water Equipment of Suburban and Rural Residents, 2005~2020

Unit: Sets/100 Households

年份 Year	城乡百户居民热水器拥有量 Possession of Hot Water Equipment	农村百户居民热水器拥有量 Possession of Hot Water Equipment	平均百户居民热水器拥有量 Average Possession of Hot Water Equipment
1995	/	/	/
1998	42.5	29	37.3
2005	74.9	57.4	68.4
2010	98	77.7	90.7
2015	98	98.0	98.0
2020	98	98	98.0

According to the increment of population in the country and the suburb area, water heater possession per 100 families and existing energy consumption for cooking and water heater per person, the LPG consumption in the country and the suburb area would reach 35 PJ by the year 2020, of which 17 PJ for cooking and 18 PJ for water heater.

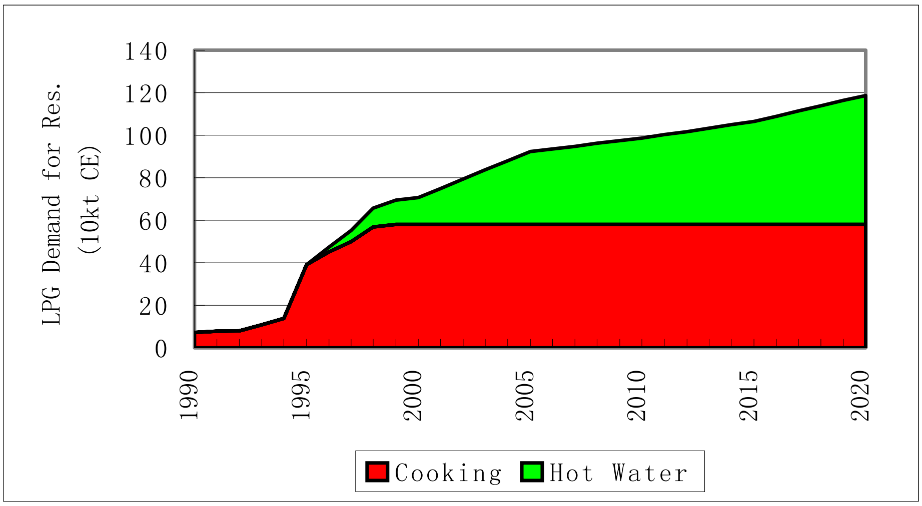

图 6-7　2000~2020 年上海市城乡居民与农村居民 LPG 需求量

Figure 6-7　LPG Demand of Suburban and Rural Residents, 2005~2020

6.4.3 Projection of Electricity Consumption for Residents

6.4.3.1Electricity Consumption Per Person

The main electricity appliances in residential living include incandescent lamp, electric fans, refrigerator, television, recorder, micro-waver and washing machine etc, of which the possession of electric fans is the largest. According to the possession of electricity appliances for year 1990~1998, the possession of color TV, air conditioner and computer saw a relatively high increment (see Table 6-12).

表6-12　　1990~1998 年上海城镇居民用电设备拥有量　　单位：台/百户

Table 6-12　Electricity Appliances Possession of Urban Residents，1990~1998 Unit: Sets/100 Households

用电设备	Appliances	1990	1995	1996	1997	1998
黑白电视机	Black/White TV Set	65	29	27		
彩色电视机	Color TV Set	77	109	113	119	128.2
电风扇	Electric Fans	187	216	224	228	229
电冰箱	Household Refrigerator	88	98	101	102	103
洗衣机	Washing Machine	72	78	82	87	91.6
录音机	Recorder	100	89	99	82	82.2
录放像机	Video Recorder	14	49	51	52	48.8
空调	Air-conditioners		33	50	62	68.6
微波炉	Microwave oven		33	45	55	62.8
影碟机	VCD players				15.2	25.4
计算机	Computers		2.2	5.2	8.6	13.2

The possession of electricity appliances in the country and the suburb area is obviously lower than that in urban area because of the low living level. Especially the possession of computer, there was almost no computer in country family in 1998, while the possession of electric fans was higher than in urban area(see Figure 6-13).

表6-13　　1990~1998 年上海农村居民用电设备拥有量 单位：台/百户

Table 6-13　　Electricity Appliances Possession of Rural Residents，1990~1998

Unit: Sets/100 Households

用电设备	Appliances	1990	1995	1996	1997	1998
黑白电视机	Black/White TV Set	74	75	72	73	68
彩色电视机	Color TV Set	25	49	53	62	74
电风扇	Electric Fans	204	270	289	302	308
电冰箱	Household Refrigerator	29	56	65	68	72
洗衣机	Washing Machine	45	63	67	67	66
录音机	Recorder	27	36	39	40	41.5
录放像机	Video Recorder		9	11	11	9
空调	Air-conditioners		1	3	4	7
微波炉	Microwave oven					7
影碟机	VCD players					8
计算机	Computers					

The electricity consumption for residents was 16.4 PJ in 1998, of which 14.0 PJ for urban area and 2.4 PJ for country area. The electricity consumption per person for urban area and suburb area were 364 kWh and 243 kWh respectively. The average electricity consumption per person for the whole municipality was 340 kWh (see Table 6-14).

表6-14　　1990~1998 年上海城镇居民与农村居民用电力消费量

Table 6-14　　Electricity Consumption by Urban and Rural Residents, 1990~1998

年份 Year	皮焦耳，PJ			人均用电量，千瓦时/人（kW.h/person）		
	城镇居民	农村居民	合计	城镇居民	农村居民	平均
1990	5.35	1.87	7.21	189	104	156
1995	8.83	1.91	10.74	256	154	229
1996	10.34	2.16	12.50	299	174	266
1997	11.42	2.22	13.65	311	215	290
1998	14.02	2.36	16.39	364	243	339

6.4.3.2 Projection of Residential Electricity Demand

The possession of electricity appliances would increase accordingly with years with the improvement of living condition. It is forecasted that good-sized color TV and refrigerator would also be the necessary electricity appliances in urban and rural area. The possession of computer would also see a significant increase with the popularization of digital communication. The possession of air conditioner in rural area would also see a rapid increase. The possession of electricity appliance is detailed in Table 6-15 and Table 6-16.

表6-15　　2005~2020 年上海城镇居民用电设备拥有量　　单位：台/百户

Table 6-15　　Electricity Appliances Possession of Urban Residents，2005~2020

Unit: Sets/100 Households

用电设备	Appliances	2005	2010	2015	2020
彩色电视机	Color TV Set	160	182	202	218
电风扇	Electric Fans	245	248	249	250
电冰箱	Household Refrigerator	115	122	129	135
洗衣机	Washing Machine	98	99.6	100	100
录音机	Recorder	70	60	50	40
录放像机	Video Recorder	72	81	89	92
空调	Air-conditioners	80	85	90	95
微波炉	Microwave oven	86.5	93.5	98	100
影碟机	VCD players	50	60	70	76
计算机	Computers	40	55	70	88

表6-16　　2005~2020 年上海农村居民用电设备拥有量　　单位：台/百户
Table 6-16　　Electricity Appliances Possession of Rural Residents，2005~2020
Unit: Sets/100 Households

用电设备	Appliances	2005	2010	2015	2020
彩色电视机	Color TV Set	92	105	117	126
电风扇	Electric Fans	330	334	335	336
电冰箱	Household Refrigerator	80	85	90	94
洗衣机	Washing Machine	75	78	80	82
录音机	Recorder	41	37	32	25
录放像机	Video Recorder	32	45	52	58
空调	Air-conditioners	11	15	22	30
微波炉	Microwave oven	46	60	73	80
影碟机	VCD players	30	42	49	56
计算机	Computers	13	18	26	36

According to the population increment and the increasing trend of electricity appliance possession in urban and rural area, it is forecasted that residential electricity demand would reach 20.4 billion kWh by the year 2000 (Figure 6-8). The residential electricity demand per person would be 1274 kWh as illustrated in Figure 6-9.

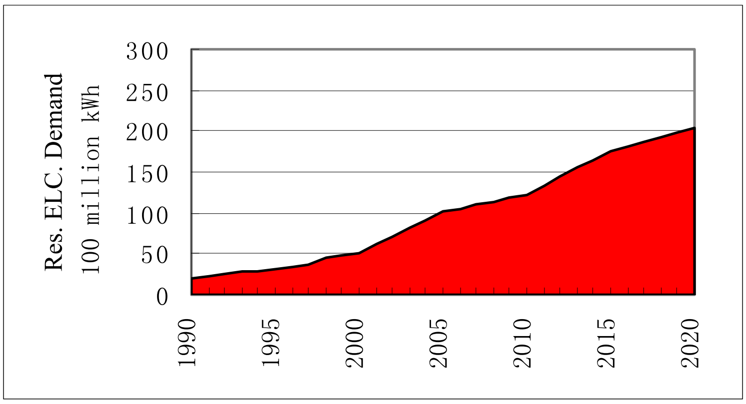

图 6-8　　2000~2020 年上海市居民生活用电需求
Figure 6-8　　Residential Electricity Demand, 2000~2020

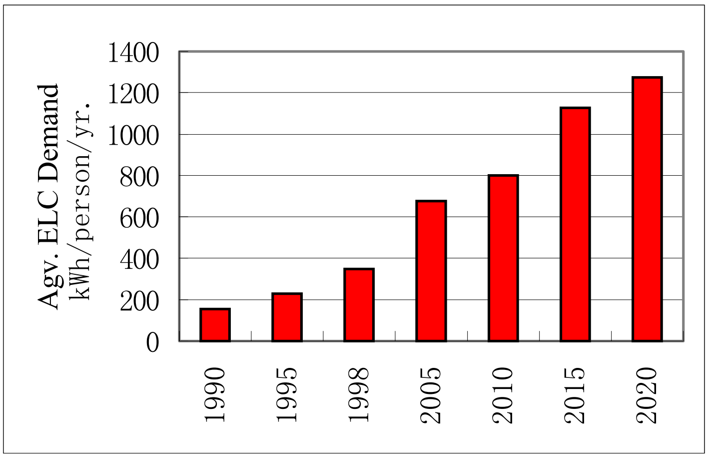

图 6-9　　2005~2040 年上海市居民生活人均用电量
Figure 6-9　　Residential Electricity Demand per Person, 2005~2040

6.4.4 Total of Residential Energy Demand

6.4.4.1 Final Energy Demand for Residential Use

According to the projection above, the residential energy demand would reach 152 PJ in total by the year 2020, of which 44 PJ for gas, 35 PJ for LPG and 74 PJ for electricity. Total energy demand would increase by 1.9 times by the year 2020 in comparison with that in 1998, of which demand for gas, LPG, electricity would increase by 1.5, 0.8 and 3.5 times respectively (see Table 6-17 and Figure 6-10).

表6-17　　2005~2020 年上海市居民生活终端能源需求　　单位：PJ

Table 6-17　　Final Energy Demand for Residential Use，2005~2020　　Unit: PJ

年份 Year	煤气 Coal Gas	液化气 LPG	电力 Electricity	合计 Total
1995	14.8	11.5	10.7	37.1
1998	17.8	19.3	16.4	53.4
2005	30.2	27.1	36.5	93.8
2010	33.5	28.9	44.1	106.6
2015	37.5	31.2	63.3	132.0
2020	43.7	34.8	73.5	152.0

Gas demand and LPG demand per person by the year 2020 would increase by 1.0 and 0.5 times, and the electricity demand per person would see a significant increase. By the year 2020, total energy demand per person would reach 324 kg CE, which is 1.3 times as that in 1998. Residential energy-consuming fashion in Shanghai would be turn around to entertainment model from exiting subsistence model (see Table 6-18).

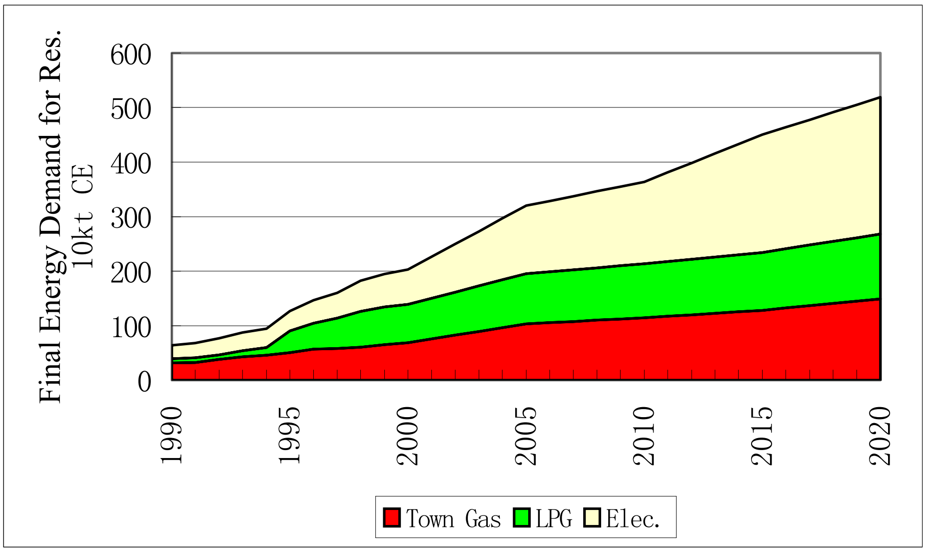

图 6-10　　2005~2020 年上海市居民生活用能需求

Figure 6-10　　Final Energy Demand for Residential Use, 2005~2020

表6-18　　2005~2040 年上海市居民生活人均用能

Table 6-18　　Projection of Residential Energy Demand per Person，2005~2040

年份 Year	人均用能，万吨标煤（kg CE/Person）			
	煤气 Coal Gas	液化气 LPG	电力 Electricity	合计 Total
1990	24.9	5.7	19.2	49.8
1995	38.9	30.1	28.1	97.2
1998	46.4	50.3	42.8	139.5
2005	68.7	61.5	83.1	213.3
2010	74.8	64.5	98.3	237.6
2015	82.0	68.3	138.4	288.6
2020	93.3	74.3	156.6	324.1

6.4.4.2 Projection of Useful Energy Demand for Residential Use

According to the energy efficiency of various facilities given in Table 6-9, 16.25%，36.2% and 90% are taken for energy efficiencies for cooking, water heater and electricity appliance respectively. The calculation result shows that the total useful energy demand including gas, GAS and electricity would reach 86.9 PJ by the year 2020 from 14.4 PJ in 1995.

表6-19　　2005~2040 年上海市居民生活有用能需求

Table 6-19　　Useful Energy Demand for Residential Use，2005~2040

年份 Year	生活有用能需求，皮焦耳（PJ）			
	煤气 Coal Gas	液化气 LPG	电力 Electricity	合计 Total
1995	2.91	1.87	9.67	14.44
1998	3.48	3.63	14.75	21.86
2005	7.09	6.41	32.87	46.36
2010	8.16	7.09	39.68	54.93
2015	9.45	7.91	56.96	74.33
2020	11.55	9.22	66.11	86.87

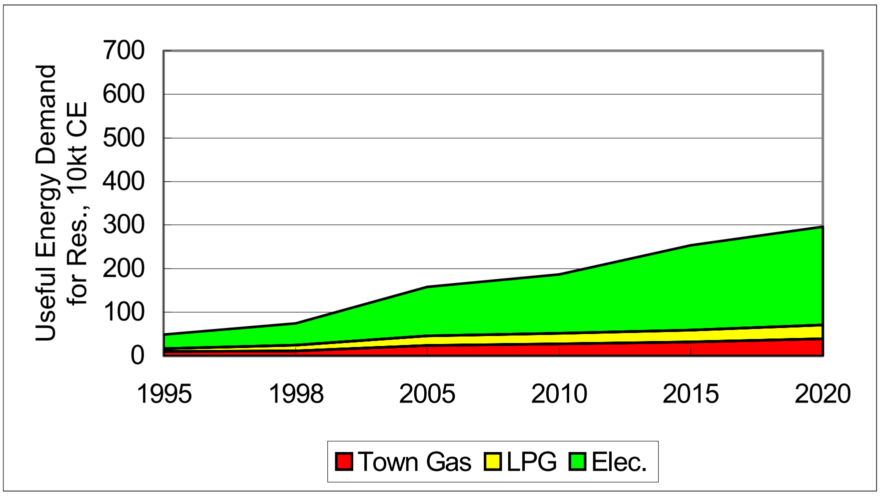

图 6-11　　2005~2020 年上海市居民生活有用能需求

Figure 6-11　　Useful Energy Demand for Residential Use, 2005~2020

6.5 Projection of Energy Demand for Transportation

6.5.1 Relationship between Vehicle Population and GDP Index

In order to forecast the increment of vehicle in Shanghai, information on vehicle population and GDP index for 1955~1998 was collected. According to statistic, these two factors shows good linearity relationship (see Figure 6-12).

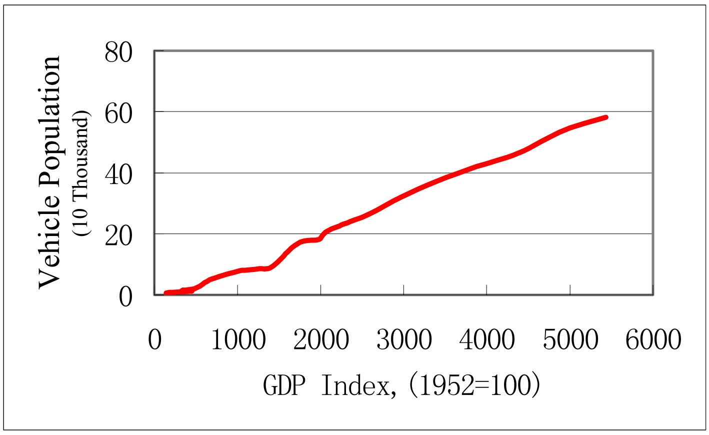

图 6-12　　上海市机动车拥有量与 GDP 指数的关系 (GDP 指数 1952 年=100)

Figure 6-12　　Relation between Vehicle Population and GDP Index
(GDP Index 1952=100)

6.5.2 Projection of Vehicle Population

According to the scenario of GDP increment, vehicle population would reach 2~3 million by the year 2020 from 0.58 million in 1998. The net vehicle population increased would be 2.5~4.3 times as the vehicle population in1998 (see Figure 6-13).

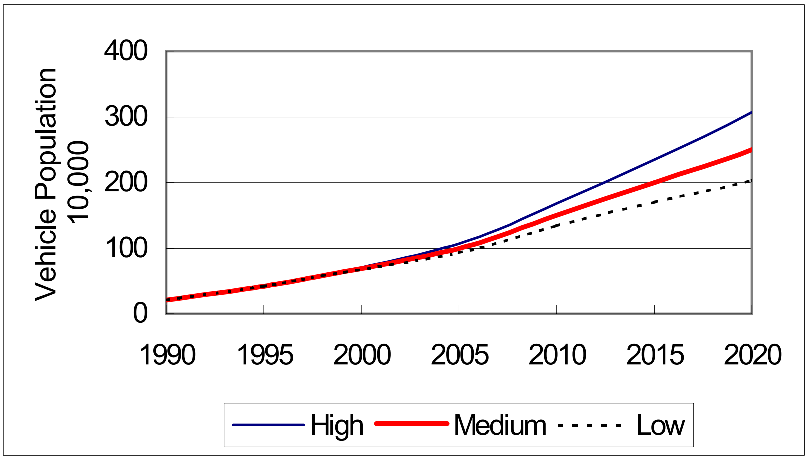

图 6-13　　2005~2020 年上海市机动车拥有量增长

Figure 6-13　　The Growth of Vehicle, 2005~2020

6.5.3 Projection of Energy Demand for Vehicle

6.5.3.1 Final Energy Demand for Vehicle

According to scenario of vehicle increment in Shanghai, energy demand for transportation would reach 254~384 PJ by the yea r2020 from 78 PJ in 1998. The net increment of fuel oil would be 2.3~3.9 times as demand of fuel oil in 1998 (see Figure 6-14).

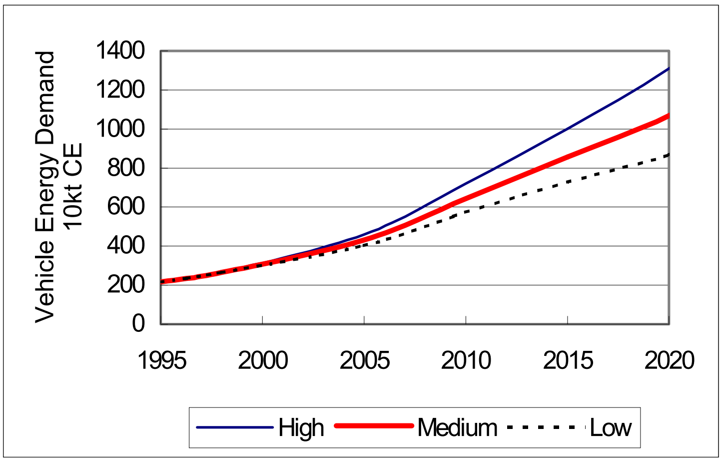

图 6-14　　2005~2020 年上海市机动车能源需求量

Figure 6-14　　Final Energy Demand for Vehicle Use, 2005~2020

6.5.3.2 Useful Energy Demand for Vehicle

According to energy efficiency of various facilities showed in Table 6-9, 32%,22%, 20%, 18% and 12% are taken for average energy efficiency for diesel vehicle, gasoline vehicle, gasoline motorcycle, gasoline light duty motorcycle and gasoline mopeds respectively. The total population of gasoline mopeds would be limited to 0.1 million by the year 2005, and gasoline mopeds would be eliminated by the year 2010. According to the limits above, the useful energy demand would reach 61~92 PJ by the year 2020 from 15 PJ in1995 (see Figure 6-15).

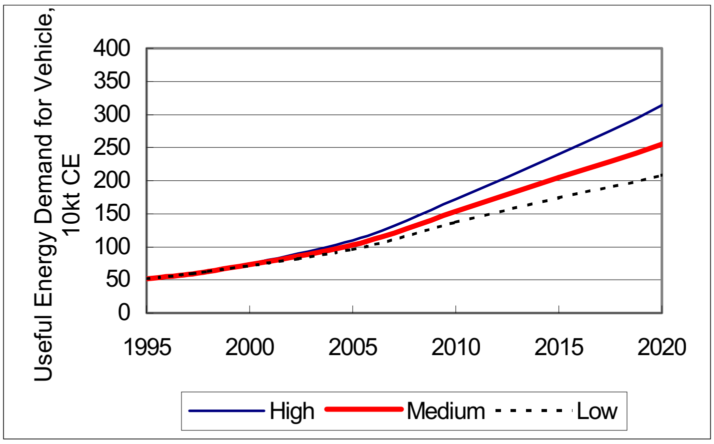

图 6-15　　2005~2020 年上海市机动车有用能需求

Figure 6-15　　Useful Energy Demand for Transportation Use, 2005~2020

6.6 Projection of Energy Demand for Off-road Transportation

Off-road transportation in Shanghai is mainly referred to train, ship and plane etc.

6.6.1 Projection of Train Energy Demand

According to Chapter 2, freight traffic volume by train per year kept at 44.21~64.16 million ton for 1980~1998. The average volume was 53 million ton per year. As showed by the statistic, number of passengers transported by train increased with years during 1980~1998 with the highest volume of 27.6 million in 1998. The departing/arriving frequency of train was 180 couple per day in 1998, of which 103 for passenger train and 77 for goods train. Diesel consumption for 1998 was 19148 ton, i.e 0.82 PJ.

The energy demand would keep at the level in 1998 as it is forecasted that there would not be much change in transportation

6.6.2 Projection of Energy Demand for Ship

According to investigation, the total number of ship passing by Shanghai harbour was 0.3194 billion. Among these, the number of ship with capacity more than 3000 ton was 13800, the number of ship with capacity lower than 3000 ton was 150100 and the number of ship sailing in the freshwater was 155500.

By the end of 1998, there was 13 berths for container in Shanghai with capacity of 2.3 billion TEU per year.

In order to meet the transportation requirement in the peripheral area, the prophase work of setting up a deep water harbor in Yangshan is now under preparation. It is forecasted that the ultimate capacity of freight traffic would reach 22~25 billion TEU of which 5.2 billion TEU for containers generated in Shanghai.

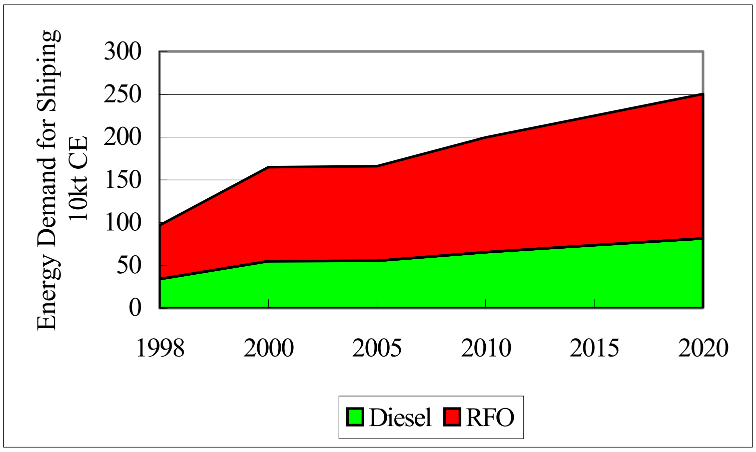

图 6-16　　　2005~2040 年上海市船舶运输能源需求量

Figure 6-16　　　Ship Transport Energy Demand, 2005~2040

According to the volume of containers transported by ship with capacity more than 3000 ton and the oil consumption of 28 PJ of which 10 PJ for diesel and 18 PJ for fuel oil), the energy demand for ship transportation by the year 2020 would reach 73 PJ (see Figure 6-16).

6.6.3 Projection of Energy Demand for Aviation

According to statistic, there were 203 of airplanes arriving in and departing from Shanghai per day in 1998. The total energy consumed for aviation was 4.06 million to CE. There wouldn't be much increase on the number of airplane as the transportation of Hongqiao Airport is basically in saturation situation at present. According to the development plan of Pudong International Airport, it is forecasted that the number of airplane arriving in and departing from Shanghai would reach 1265 per day.

Kerosene consumption in aviation was 23.2 PJ in 1998. According to the number of airplane at Hongqiao Airport present and at Pudong International Airport in the future, it is forecasted that the aviation energy demand would reach 144 PJ by the year 2020 (see Figure 6-17).

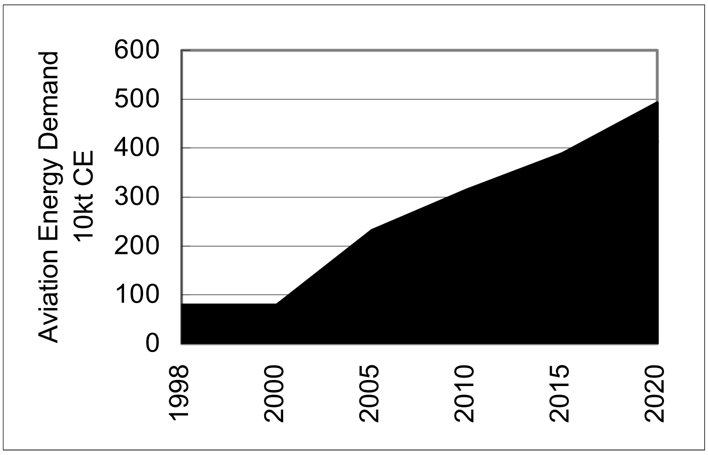

图 6-17　　2005~2020 年上海市航空用能需求量

Figure 6-17　　Final Energy Demand of Aviation, 2005~2020

6.6.4 Total Energy Demand for Off-road Transportation

6.6.4.1 Final Energy Demand for Off-road Transportation

According to the projection above, the energy demand for off-road transportation would reach 218 PJ by the year 2020, of which vessel, aviation and train accounted for 34%, 66% and 0.5% respectively.

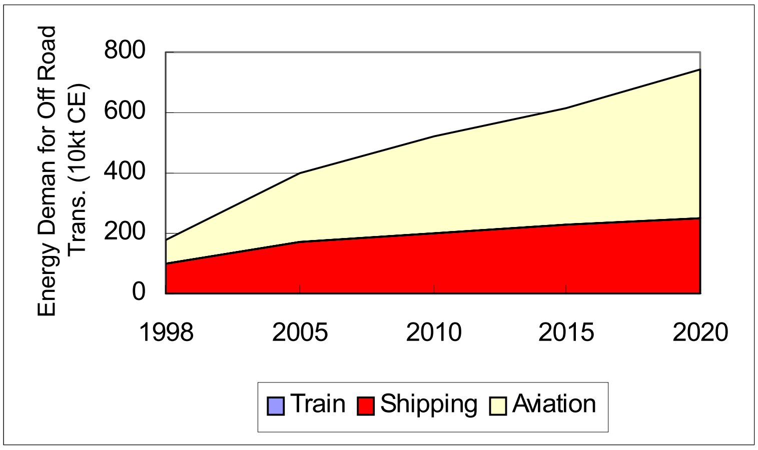

图 6-18　　　　2005~2020 年上海市非道路交通用能需求量

Figure 6-18　　　　Final Energy Demand of Off Road Transportation, 2005~2020

6.6.4.2 Useful Energy Demand for Off-road Transportation

According to energy efficiency of various facilities shown in Table 6-9, 30%, 35% and 40% would be taken for the energy efficiency for train with gas engine, vessel and aviation respectively. The calculation result shows that the energy demand for trian, vessel and aviation would reach 83.7 PJ by the year 2020 from 19.4 PJ in 1998(see Figure 6-19).

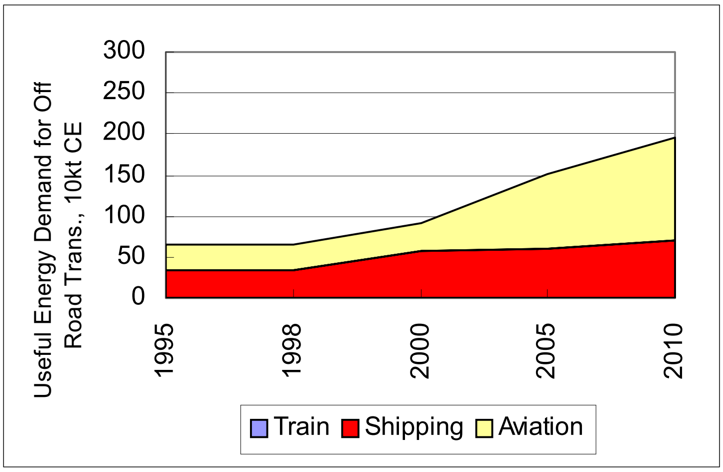

图 6-19　　　　2005~2020 年上海市非道路交通有用能需求

Figure 6-19　　　　Useful Energy Demand of Off Road Transportation, 2005~2020

6.7 Projection of Energy Demand for Agriculture

6.7.1 Projection of Agriculture GDP

According to the forecast of GDP and industry structure in Shanghai, agriculture GDP would reach 17~25.8 billion Yuan by the year 2020 which is 1.3~2.5 times as that in 1998. Increasing rate of agriculture GDP would vary in the range of 4%~60% during 1998~2020.

表6-20　　2005~2020 年上海市农业国内生产总值（1995 年价格）

Table 6-20　Agricultural GDP Value (95' price), 2005~2020

年份 Year	全市GDP，亿元（1995年价格） Total GDP, 100 million RMB			产业结构（%）	农业GDP，亿元（1995年价格） Agricultural GDP, 100 million RMB		
	高方案 Higher Speed	中方案 Medium Speed	低方案 Lower Speed		高方案 Higher Speed	中方案 Medium Speed	低方案 Lower Speed
1995	2463	2463	2463	2.5	61.7	61.7	61.7
1998	3453	3453	3453	2.1	73.5	73.5	73.5
2005	7233	6759	6312	1.5	109.9	102.7	95.9
2010	11387	10164	9062	1.3	146.9	131.1	116.9
2015	17122	14591	12415	1.1	195.2	166.3	141.5
2020	25746	20948	17010	1.0	257.5	209.5	170.1

6.7.2 Elasticity Coefficient of Agriculture Energy Consumption

According to the statistics for 1995~1998, the agriculture GDP in 1998 was 7.85 billion Yuan in Shanghai together with energy consumption of 0.7382 million ton CE. As converted to 1995 price, energy consumption varied from 0.85 to 1.09 ton CE per 10000 Yuan agriculture GDP during 1995~1998, of which 1.0 ton CE per 10000 Yuan agriculture GDP for 1998.

Elasticity coefficient of agriculture energy consumption for 2005~2040 is detailed in Table 6-19.

表6-21　　2005~2020 年上海市农业能源需求弹性系数

Table 6-21　Agricultural Energy Demand Elasticity, 2005~2020

年份 Year	农业万元GDP能源消费量 Energy Demand per 10 thousand GDP	能源消费弹性系数（能源法） Energy Demand Elasticity
2000-2005	0.99~0.92	1.49~1.59
2005~2010	0.92~0.85	0.68~0.77
2010~2015	0.85~0.79	0.64~0.75
2015~2020	0.79~0.72	0.59~0.73

6.7.3 Projection of Agriculture Energy Demand

6.7.3.1 Final Agriculture Energy Demand

As shown in forecasting result, agriculture energy demand would reach 36.1~54.8 PJ by the year 2020 which is 1.7~2.5 times as that in 1998. Increasing rate of agriculture energy demand would vary in the range of 2%~4% during 1998~2020 (see Figure 6-20).

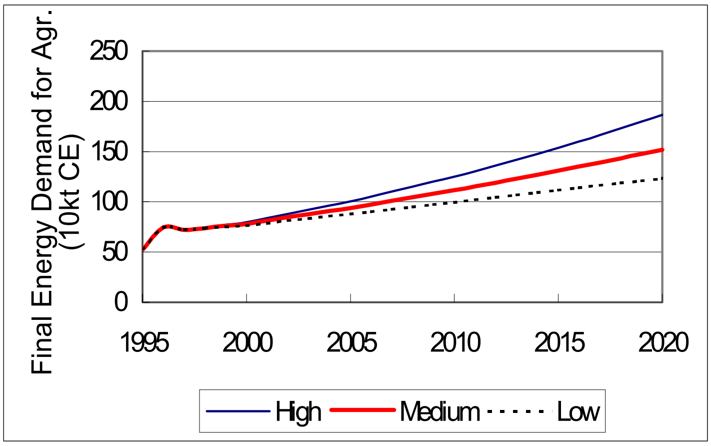

图 6-20 2005~2020 年上海市农业能

Figure 6-20 Final Energy Demand for Agricultural Use, 20 源需求量 05~2020

6.7.3.2 Useful Energy Demand for Agriculture

According to the energy efficiency shown in Table 6-9, 63%, 20%, 30% and 87% are taken for the energy efficiency of coal-burning boiler, gasoline-burning, kerosene-burning, diesel-burning and electricity-consumed facility respectively. The calculation result shows that the useful energy demand for agriculture would reach 14~21 PJ by the year 2020 from 8.4 PJ in 1998 (see Figure 6-21).

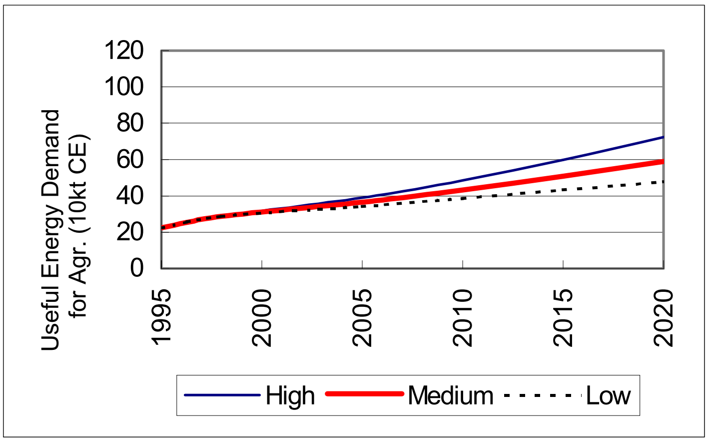

图 6-21 2005~2020 年上海市农业有用能需求

Figure 6-21 Useful Energy Demand for Agricultural Use, 2005~2020

6.8 Projection of Energy Demand for Commerce

6.8.1 Projection of Commerce GDP

According to the adjustment policy of industry structure, the tertiary industry GDP would account for 55% and 60% of the total GDP for 2005 and 2010 in Shanghai.

According to the increment of GDP and industry structure, it is forecasted that the tertiary industry GDP would reach 1020.6~1544.7 billion Yuan by the year 2020 which is 6~9 times as that in 1998

(165 billion Yuan). The increment rate of commerce GDP would be in the range of 9%~11% for the year 1998~2020.

表6-22　　2005~2020 年上海市第三产业国内生产总值（1995 年价格）

Table 6-22　Tertiary Industry GDP Value (95' price), 2005~2020

年份 Year	全市GDP，亿元（1995年价格） Total GDP, 100 million RMB			产业结构 （%）	第三产业GDP，亿元（1995年价格） 3rd Industry GDP, 100 million RMB		
	高方案 Higher Speed	中方案 Medium Speed	低方案 Lower Speed		高方案 Higher Speed	中方案 Medium Speed	低方案 Lower Speed
1995	2463	2463	2463	40.2	991	991	991
1998	3453	3453	3453	47.8	1650	1650	1650
2005	7233	6759	6312	55.0	3978	3718	3472
2010	11387	10164	9062	56.7	6453	5759	5135
2015	17122	14591	12415	58.3	9988	8512	7242
2020	25746	20948	17010	60.0	15447	12569	10206

6.8.2 Elasticity Coefficient of Commerce Energy Consumption

According to the tertiary industry GDP and its energy consumption for 1995~1998, the decrement rate of energy consumption per 10000 Yuan was basically kept at 0.95% per year. Elasticity coefficient of commercial energy demand for 2005~2020 was shown in Table 6-23.

表6-23　　2005~2020 年上海市商业能源需求弹性系数

Table 6-23　Commercial Energy Demand Elasticity, 2005~2020

年份 Year	商业万元GDP能源消费量 Energy Demand per 10 thousand GDP	能源消费弹性系数（能源法） Energy Demand Elasticity
1995~2000	0.42~0.40	0.94
2000-2005	0.40~0.35	0.90~0.91
2005~2010	0.35~0.32	0.79~0.82
2010~2015	0.32~0.28	0.72~0.77
2015~2020	0.28~0.25	0.68~0.75

6.8.3 Projection of Commerce Energy Demand

6.8.3.1 Final Commerce Energy Demand

According to the energy consumption per unit of 1000 Yuan GDP and elasticity coefficient of energy consumption, the energy demand of commercial activities would reach 283~541 PJ by the year 2020 which is 4.0~7.7 times as that in 1998 (70 PJ) (see Figure 6-22). The energy demand under various economy increasing speeds is illustrated in Figure 6-23~ Figure 6-25.

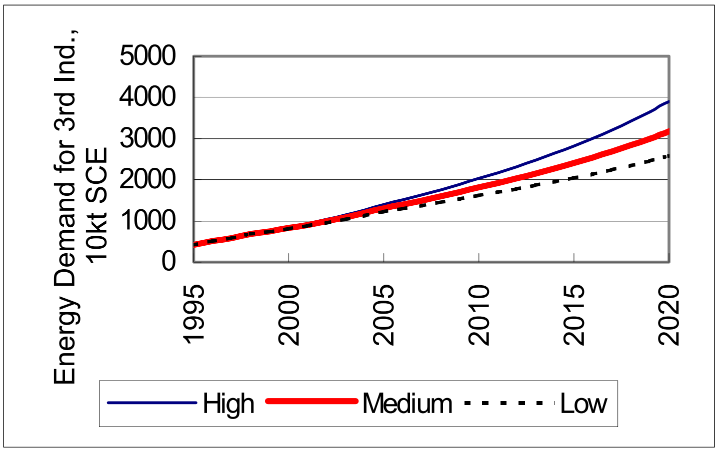

图 6-22　　　　2005~2020 年上海市第三产业能源需求量

Figure 6-22　　　　Final Energy Demand for Tertiary Industry Use, 2005~2020

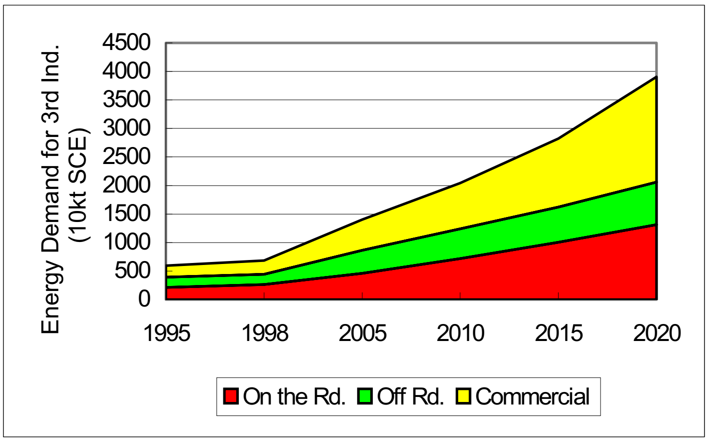

图 6-23　　　　2005~2020 年上海市第三产业分部门能源需求量(高方案)

Figure 6-23　　　　Final Energy Demand for Sub-sectors of Tertiary Industry, 2005~2020 (With Higher Economic Growth Rate)s

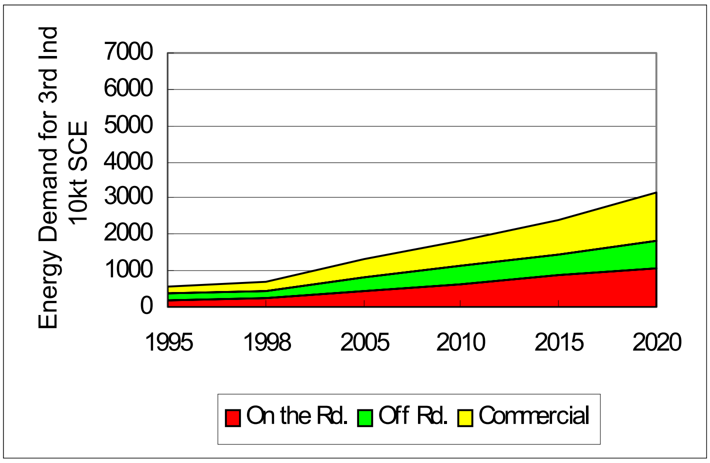

图 6-24　　　　2005~2020 年上海市第三产业分部门能源需求量(中方案)

Figure 6-24　　　　Final Energy Demand for Sub-sectors of Tertiary Industry, 2005~2020 (With Medium Economic Growth Rate)

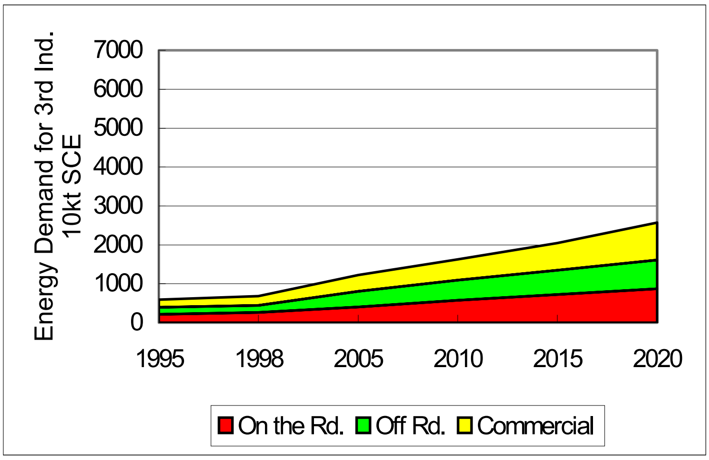

图 6-25 2005~2020 年上海市第三产业分部门能源需求量(低方案)

Figure 6-25 Final Energy Demand for Sub-sectors of Tertiary Industry, 2005~2020 (With Lower Economic Growth Rate)

6.8.3.2 Useful Energy Demand for Commerce

According to the energy efficiency shown in Table 6-9, 63%, 22%, 25%, 32% and 90% are taken for the energy efficiency of boiler, gasoline-burning, kerosene-burning, diesel-burning and electricity-consumed facility respectively. The calculation result shows that the useful energy demand for commerce would reach 204~354 PJ by the year 2020 from 52 PJ in 1998 (see Figure 6-26).

The useful energy demand for commerce under various economy increasing speeds is illustrated in Figure 6-27~ Figure 6-29.

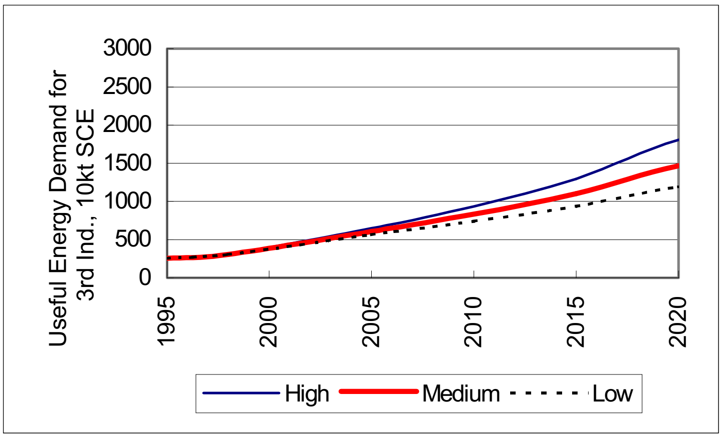

图 6-26 2005~2020 年上海市第三产业有用能需求

Figure 6-26 Useful Energy Demand for Tertiary Industry Use, 2005~2020

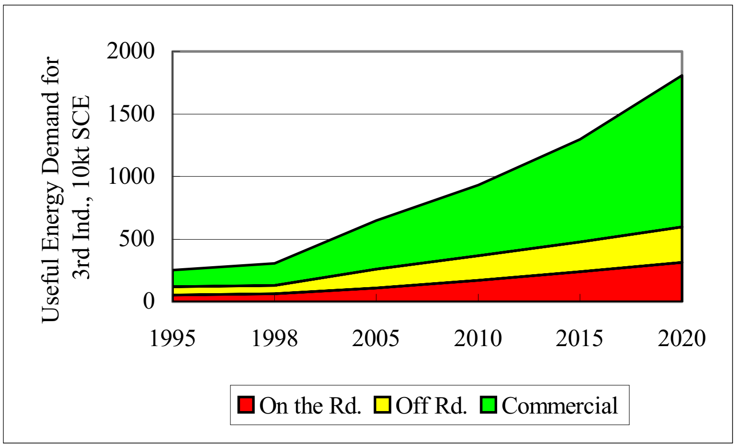

图 6-27　　2005~2040 年上海市第三产业分部门有用能需求量(高方案)

Figure 6-27　　Useful Energy Demand for Sub-sectors of Tertiary Industry, 2005~2040 (With Higher Economic Growth Rate)

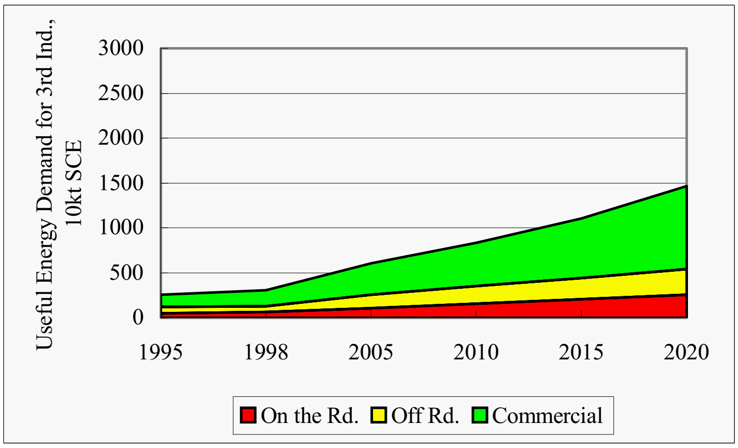

图 6-28　　2005~2020 年上海市第三产业分部门有用能需求量(中方案)

Figure 6-28　　Useful Energy Demand for Sub-sectors of Tertiary Industry, 2005~2020 (With Medium Economic Growth Rate)

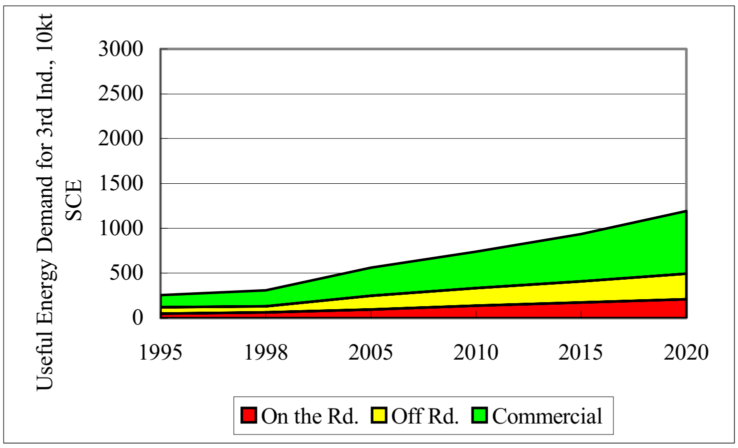

图 6-29　　2005~2020 年上海市第三产业分部门有用能需求量(低方案)

Figure 6-29　　Useful Energy Demand for Sub-sectors of Tertiary Industry, 2005~2020 (With Lower Economic Growth Rate)

6.9 Projection of Energy Demand for Industry

6.9.1 Projection of Industry GDP

According to the increment of GDP and industry structure, it is forecasted that the industry GDP would reach 663.4~1004.1 billion Yuan by the year 2020 which is 4.3~6.5 times as that in 1998 (154.2 billion Yuan). The increment rate of commerce GDP would be in the range of 7%~9% for the year 1998~2020.

表6-24　　2005~2020 年上海市工业国内生产总值（1995 年价格）

Table 6-24　Industrial GDP Value (95' price), 2005~2020

年份 Year	全市GDP，亿元（1995年价格） Total GDP, 100 million RMB			产业结构 （%）	工业GDP，亿元（1995年价格） Industry GDP, 100 million RMB		
	高方案 Higher Speed	中方案 Medium Speed	低方案 Lower Speed		高方案 Higher Speed	中方案 Medium Speed	低方案 Lower Speed
1995	2463	2463	2463	57.2	1410	1410	1410
1998	3453	3453	3453	44.6	1542	1542	1542
2005	7233	6759	6312	43.5	3145	2939	2744
2010	11387	10164	9062	42.0	4787	4273	3810
2015	17122	14591	12415	40.5	6939	5913	5031
2020	25746	20948	17010	39.0	10041	8170	6634

6.9.2 Elasticity Coefficient of Industry Energy Consumption

As Shanghai now is at the phase of industry structure adjustment and industry layout adjustment, therefore the elasticity coefficient of industry energy consumption is relatively low in the period of 1995~2000. According to the optimistic estimation, the adjustment would last 5 years or even more. The industry development would transfer the focus onto high-tech sectors with low energy consumption and less pollution. It would still see a decrease in energy consumption per unit GDP. Elasticity coefficient of industry energy demand for 2005~2020 was shown in Table 6-25.

表6-25　　2005~2040 年上海市工业能源需求弹性系数

Table 6-25　Industrial Energy Demand Elasticity, 2005~2040

年份 Year	工业万元GDP能源消费量 Energy Demand per 10 thousand GDP	能源消费弹性系数（能源法） Energy Demand Elasticity
1995~2000	1.82~1.26	0.05~0.16
2001-2005	1.26~0.93	0.16~0.29
2006~2010	0.93~0.70	0.19~0.36
2011~2015	0.70~0.56	0.25~0.45
2016~2020	0.56~0.44	0.28~0.39

6.9.3 Projection of Industry Energy Demand

6.9.3.1 Final Industry Energy Demand

According to the decrement trends of energy consumption per unit of 1000 Yuan GDP and the increment of industry GDP, the final energy demand for industry would reach 963~1393 PJ by the year 2020 from 738 PJ in 1998. The increasing rates for the final energy industry would be in the range of 1.2%~3.0% for 1998~2020(see Figure 6-30).

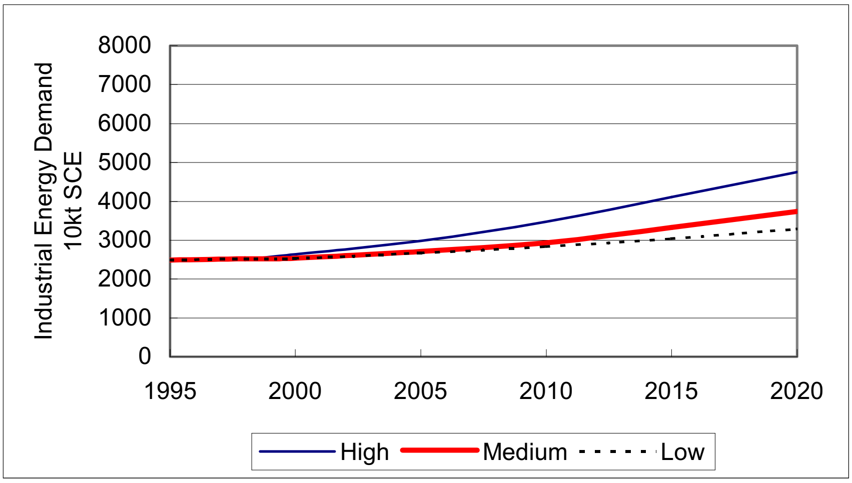

图 6-30 2005~2020 年上海市工业能源需求量

Figure 6-30 Final Energy Demand for Industry Use, 2005~2020

6.9.3.2 Useful Energy Demand for Industry

According to the energy efficiency shown in Table 6-9, the useful energy demand for industry would reach 496~695 PJ by the year 2020 which is 1.13~1.58 times as that in 1998 (439 PJ). The increasing rates of the useful energy demand would be in the range of 0.6%~2% for 1998~2020.

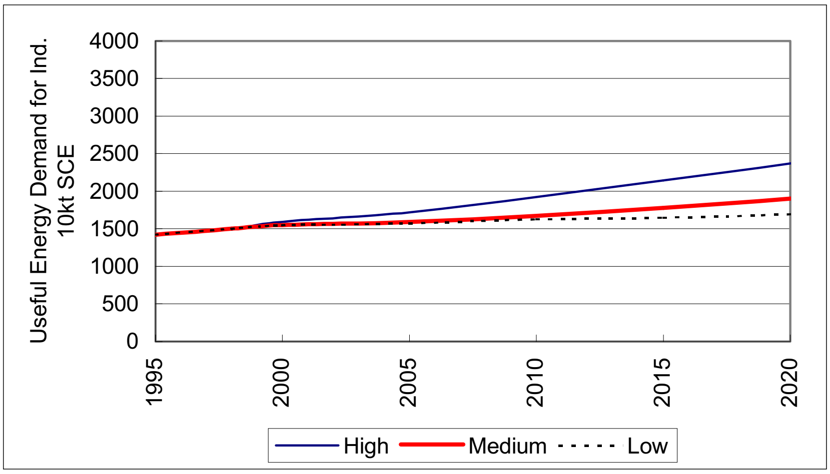

图 6-31 2005~2020 年上海市工业有用能需求量

Figure 6-31 Useful Energy Demand for Industry Use, 2005~2020

6.10 Total Energy Demand in Shanghai

6.10.1 the Final Energy Demand

Energy projection results indicate that the final energy demand would reach 1907~2744 PJ by the year 2020 from 1014 PJ in 1998. The proportion of final energy demand for agriculture to the total final energy demand in Shanghai would reduce to 2% by the year 2020 from 2.1% in 1998 and that of industry would reduce to 49% from 73%. While the proportion of commerce, on-road transportation, off-road transportation and living would increase to 18%, 14%, 10% and 7% from 6.9%, 7.7%, 5.2% and 5.3%. The final energy consumption for 2020 would be 1.9~2.7 times as that in 1998.

By the year 2020, the final energy consumption of the primary industry would account for 2% of the total final energy consumption in Shanghai, that of the secondary industry would reduce to 49% from 73%, that of the tertiary industry would increase to 42% from 20%, that of living would increase to 7% from 5.3%.

6.10.2 Useful Energy Demand

The projection results show that final useful energy demand would reach 946~1333 PJ by the year 2020 from 574 PJ in 1998. The proportion of the useful energy demand for agriculture to the total useful energy demand in Shanghai would increase to 2% from 1% and that of industry would reduce to 50% from 80%. While the proportion of commerce, on-road transportation, off-road transportation and living would increase to 25%, 7%, 8% and 8% from 9%, 3%, 3% and 4%. The final useful energy consumption for 2020 would be 1.6~2.3 times as that in 1998.

6.11. Conclusion

According to the population increment, economy increasing speed and industry structure, the projection is detailed as belows:

(1) By the year 2020, the final energy demand would reach 1907~2744 PJ of which that for agriculture, industry, commerce, on-road, off-road and living would be 1.7~2.5 times, 1.3~1.9 times, 4.0~7.7 times, 3.3~4.9 times and 4.2 times as that in 1998 respectively. The total final energy demand would be 1.9~2.7 times as that in 1998.

(2) By the year 2020, the final energy demand for agriculture, industry, commerce, on-road, off-road and living would account for 2%, 49%, 18%, 14%, 10% and 7% of the total final energy demand in Shanghai.

(3) By the year 2020, the final useful energy demand would reach 946~1333 PJ, of which the final useful energy demand for agriculture, industry, commerce, on-road, off-road and living would account for 2%, 50%, 25%, 7%, 8% and 8% of the total final energy demand in Shanghai. The total useful energy demand by the year 2020 would be 1.6~2.3 times as that in 1998.

(4) The increasing rates for the final energy demand for agriculture, industry, commerce, on-road, off-road and living would be in the range of 2%~4%, 1.2%~2.9%, 6.6%~9.2%, 5.5%~7.5%, 6.7% and 4.9% respectively。

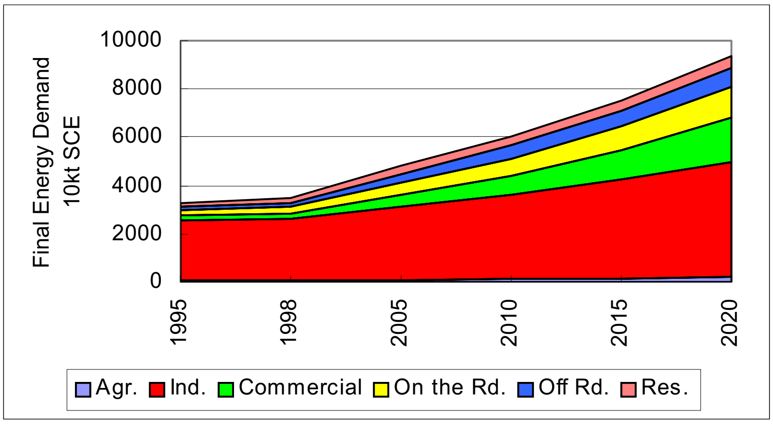

图 6-32　　2005~2020 年上海市终端各部门能源需求量(高方案)
Figure 6-32　　Final Energy Demand for Different Sectors, 2005~2020 (With Higher Economic Growth Rate)

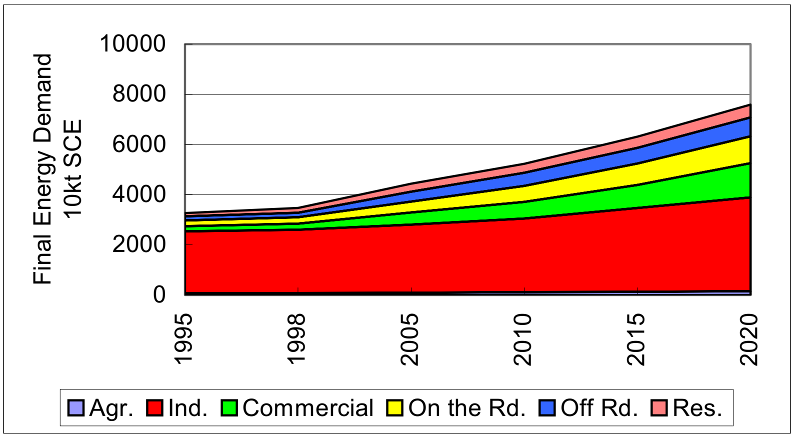

图 6-33　　2005~2020 年上海市终端各部门能源需求量(中方案)
Figure 6-33　　Final Energy Demand for Different Sectors, 2005~2020 (With Medium Economic Growth Rate)

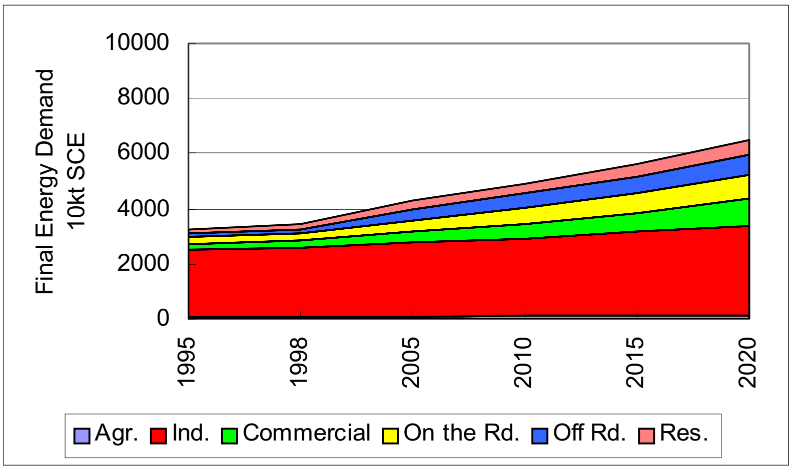

图 6-34　　2005~2020 年上海市终端各部门能源需求量(低方案)
Figure 6-34　　Final Energy Demand for Different Sectors, 2005~2020 (With Lower Economic Growth Rate)

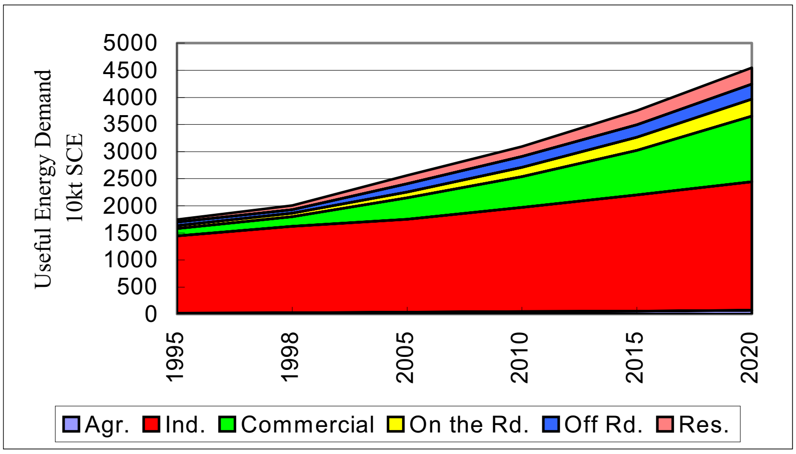

图 6-35 2005~2020 年上海市终端各部门有用能需求(高方案)

Figure 6-35 Useful Energy Demand for Different Sectors, 2005~2020 (With Higher Economic Growth Rate)

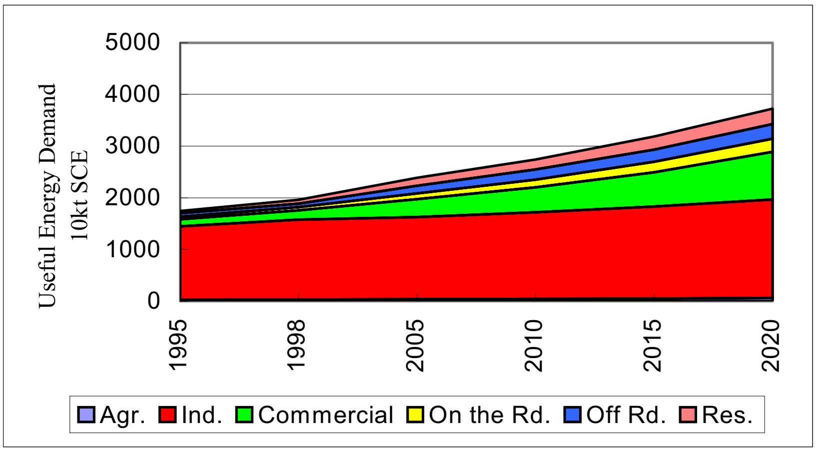

图 6-36 2005~2020 年上海市终端各部门有用能需求(中方案)

Figure 6-36 Useful Energy Demand for Different Sectors, 2005~2020 (With Medium Economic Growth Rate)

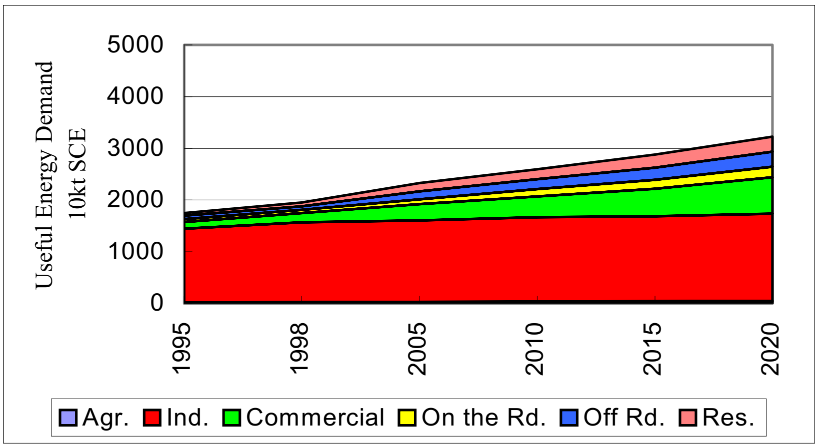

图 6-37 2005~2020 年上海市终端各部门有用能需求(低方案)

Figure 6-37 Useful Energy Demand for Different Sectors, 2005~2020 (With Lower Economic Growth Rate)

7. Future Energy Option and Emission Reduction

7.1 Introduction

The purpose of this study is to explore the long-term prospect of Shanghai energy system including energy demand and supply, and to distinguish energy option and its benefits on emission reduction and public health. To achieve this objective, a MARKet ALLocation model (MARKAL) was used for energy option and emission reduction analysis.

As an energy system model, MARKAL links energy supply, energy conversion and energy demand sectors of nation or a region. MARKAL is a flexible, multi-time-period, linear-programming model of a generalized energy system. It was originally designed for the evaluation of the possible impacts of new technologies on national or a regional wide. It can be applied to scenarios or cases, which embody a variety of assumptions or restrictions. The results produced by MARKAL model are an optimal solution of energy supply and consumption with environmental emissions on the assumed constraints related to the system, which provided by users according to the specific case.

7.2 Shanghai Energy Reference System

Shanghai reference energy system at present was built upon the framework of MARKAL model, and long-term economic development was input by means of useful energy demand of different sectors.

The purpose of this study was to explore the possibility of reducing SO_2, NOx, PM_{10} and CO_2 emission from Shanghai energy system, and health benefit of emission reductions from long-term of point of view.

7.2.1 Energy Carriers

In the energy reference system there were 23 energy carriers, which can be distinguished into two categories:

1. Primary Energy Carriers

    HCO: Hard Coal
    CCO: Coking Coal
    GAS: Natural Gas from Western China
    OLH: Heavy Crude Oil
    OLL: Light Crude Oil
    HYD: Hydro-Power from Three Gorges Project
    WIN: Wind Power
    SOL: Solar PV

2. Secondary Energy Carriers

    BFG: Blast Furnace Gas
    COG: Coke Oven Gas

COK: Coke
DSL: Diesel
GOL: Gas Oil
GSL: Gasoline
HCG: Hard Coal Gas
HTS: High Temperature Steam
KER: Kerosene
LPG: Liquefied Petroleum Gas
LTS: Low Temperature Steam
MET: Methanol
NAP: Naphtha
PCK: Petroleum Coke
RFO: Residual Fuel Oil

7.2.2 Energy Demand Sectors

There were five energy demand sectors in Shanghai reference system including AGRICULTURE, INDUSTRY, COMMERCIAL, TRANSPORTATION, and RESIDENTIAL. The above five energy demand sectors were further breakdown into 30 sub-sectors according to final demand technologies.

7.2.3 Demand Technologies

According to the type of energy carriers used by demand technologies and energy services provided to end-use sectors, 71 types of demand technologies were defined. Of which 2 were for AGRICULTURE, 42 for INDUSTRY, 14 for COMMERCIAL, 22 for TRANSPORTATION, and 21 for RESIDENTIAL.

Following list is an example of the major demand technology consisted in INDUSTRY sector:

1. Industry Boiler Technologies:

IH1: Coal Boiler > 10 t steam/hr.
IH2: Gas Oil Boiler > 10 t steam/hr.
IH3: RFO Boiler > 10 t steam/hr.
IH5: Gas Boiler > 10 t steam/hr.
IH6: New GAS Boiler > 10 t steam/hr.
IHA: New Coal Boiler > 10 t steam/hr.
II1: Coal Boiler 4 - 10 t steam/hr.
II2: Gas Oil Boiler 4 - 10 t steam/hr.
II3: RFO Boiler 4 - 10 t steam/hr.
II5: HCG Boiler 4 - 10 t steam/hr.
II6: Gas Boiler 4 - 10 t steam/hr.
IIA: New Gas Oil Boiler 4 - 10 t steam/hr.
IIB: New RFO Boiler 4 - 10 t steam/hr.
IIC: New HCG Boiler 4 - 10 t steam/hr.
IID: New Gas Boiler 4 - 10 t steam/hr.
IIE: New Coal Boiler 4 - 10 t steam/hr.

IJ1: Coal Boiler < 4 t steam/hr.
IJ2: Gas Oil Boiler < 4 t steam/hr.
IJ3: RFO Boiler < 4 t steam/hr.
IJ5: Gas Boiler < 4 t steam/hr.
IJA: New Gas OIL Boiler < 4 t steam/hr.
IJB: New RFO Boiler < 4 t steam/hr.
IJC: New Gas Boiler < 4 t steam/hr.
IJD: New Coal Boiler < 4 t steam/hr.

2. Industry Electricity Motors:

IL1: Conventional Motor > 200 kW
IL2: VSD etc. Eff. Improvement Motor > 200 kW
IM1: Conventional Motor 0.55 - 200 kW
IM2: High Efficiency Motor 0.55 - 200 kW
IM3: VSD etc. Eff. Improvement Motor 0.55 - 200 kW

3. Steel Industry:

IS2: Electric Arc Furnace Scrap Based
IS3: Electric Arc Furnace DRI Based
IS4: Hot Rolling Steel
IS5: Cold Rolling Steel
IS6: Basic Oxygen Furnace Steel Making
IS7: Net Shape Casting

7.2.4 Conversion Technologies

There were 28 types of conversion technologies defined in Shanghai energy reference system:

E01: Coal Steam Electricity
E02: Coal IGCC
E03: Coal PFBC
E04: Coal Ultra-supercritical Steam Cycle
E05: Coal PFBC CHP
E06: Coal Steam Electric CHP
E07: Coal Ultra-supercritical Steam CHP
E08: Coal USC Steam Cycle + SCR + PM Removal
E09: Coal USC Steam CHP + SCR + PM Removal
E0A: Coal PFBC + SCR
E0B: Coal Small Scale Co-generation
E11: Nature Gas CCE
E12: Nature Gas Engine Small Co-generation
E13: Nature Gas CCE CHP
E14: Nature Gas CCE + SCR
E21: Fuel Oil Steam Cycle
E51: Blast Furnace Gas Electric
EC1: Coal Steam Electricity + SO2 Removal
EC2: Coal IGCC+ SO2 Removal
EC3: Coal PFBC+ SO2 Removal

EC4: Coal Ultra-supercritical Steam Cycle + SO2 Removal
EC5: Coal PFBC CHP + SO2 Removal
EC6: Coal Steam Electric CHP + SO2 Removal
EC7: Coal Ultra-supercritical Steam CHP + SO2 Removal
EC8: Coal USC Steam Cycle + SCR + PM Removal + SO2 Removal
EC9: Coal USC Steam CHP + SCR + PM Removal + SO2 Removal
ECA: Coal PFBC + SCR + SO2 Removal
ECB: Coal Small Scale Co-generation + SO2 Removal

7.3 Future Energy Consumption and Emissions from Energy Reference System

7.3.1 Final Energy Demand

As MARKAL is driven by energy demand of the sectors as exogenous inputs, the first step to run MARKAL is to forecast the sector energy demand for Shanghai. The energy demand depends on various factors, such as the economic growth rate of different sectors, technology used, number of population, living standards, and etc.

According to the basic requirement of MARKAL, sector energy demand was forecasted by each energy demand elasticity. The base year for energy demand forecasting was 1995. The short term GDP growth rate was elected 9-11%, which was as same as the number issued by “The Ten-Fifth Plan of Shanghai Social Economic Development” (promulgated by The 4th Meeting of the10th Shanghai People’s Congress, 7 February, 2001). And 0.5%-1.0% of GDP growth rate declined was assumed on the bases of 9-11% for every five years onward 2005 to 2020. The future annual growth rate of GDP for different sectors and city population of the study period is listed in Table 7.1.

表 7.1: *GDP 年均增长速度与人口*

Table 7.1: *Annual Growth Rate of GDP and Population*[1]

	Unit	2000-2005	2005-2010	2010-2020	2020-2030	2030-2035
Agriculture	%	5.2	4.9	4.8	4.4	3.0
Industry	%	7.6	7.8	6.7	4.5	3.5
Transportation	%	15.0	12.1	10.4	6.5	5.2
Commercial	%	14.1	8.9	7.9	4.3	3.3
Total GDP	%	9-11	7.5-9.5	6.5-8.5	4.0-5.0	3.0-4.0
Population[1)]	million	14.5	15.0	15.3-15.4	15.9-16.0	16.5

1): Including floating population.

To forecast useful energy demand, historical elasticity of final energy consumption were used for final energy demand by sectors. The useful energy demand was then translated by applying energy efficiency to final energy demand of the in-use energy technologies.

Table 7.2 and Figure 7.1 shows the useful energy demand of the study period from 2000 to 2020.

表 7.2: *各部门有用能需求*

Table 7.2: *Useful Energy Demand by Sectors[2] [PJ]*

	1995	2000	2005	2010	2015	2020
Agriculture	7	9	11	13	15	17
Industry	341	350	365	394	433	469
Transportation	15	22	30	45	60	75
Bunkers	19	26	44	57	69	83
Commercial	40	61	103	141	194	272
Residential	21	31	52	61	80	93
Total	443	499	605	711	851	1010

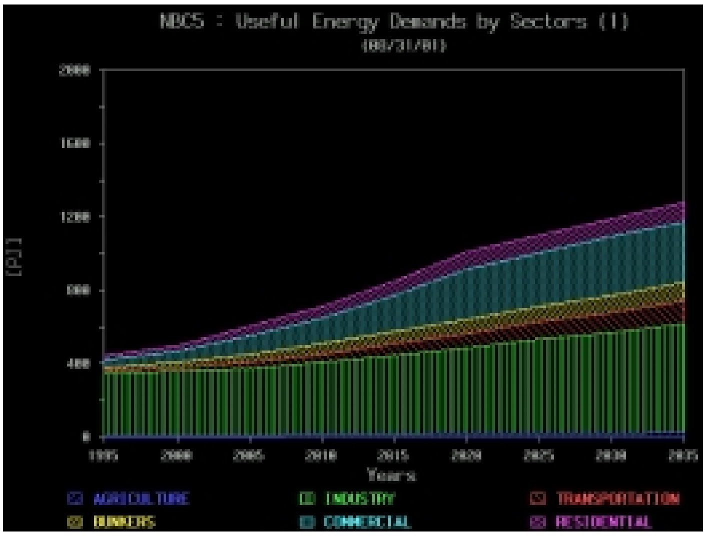

图 7.1: *各部门有用能需求*

Figure 7.1: *Useful Energy Demand by Sectors[3]*

7.3.2 Primary Energy Consumption

For projecting primary energy consumption of the existing energy reference system, there were three premises assumed in this study:

1. No extra natural gas supplied except the one from East China;
2. There were no constraint on coal supply;
3. Electricity supply depends on Shanghai energy reference system itself.

The first premise is coincident with the present situation in Shanghai. The second and third one is future baseline of Shanghai, it will show energy consumption and emission from energy reference system if no more energy and environmental policies.

Table 7.3 and Figure 7.2 show the results produced by MARKAL from Shanghai reference energy system under the above three premises. People can easily find that to meet the final energy demand of future social economic development, the total primary energy consumption will be increased to 2600 PJ, being 1.9 times of the base year 1995. Coal consumption of the energy reference system will be increased 81%. Crude oil consumption will be increased 103% in 2020

[1] C:\My Documents\Chen Changhong\美国 EPA 项目\能源与健康\英文报告\第二阶段英文报告\Shanghai_MARKAL_Emission 情景(修改_01).xls

[2] MARKAL: FED1

on the base year 1995 for fuel production to meet fuel requirement of fast growth of vehicle population in the next decades.

As the city switching its conventional industrial activity to service or commercial sectors, the total primary energy consumption per unit GDP in 2020 will be declined obviously.

表 7.3: *一次能源消费与能源消费指标*

Table 7.3:*Primary Energy Consumption[4] and its Energy Consumption Indicators*

	Unit	1995	2000	2005	2010	2015	2020
Solid Fuel	PJ	1032	1136	1321	1423	1620	1869
Liquid Fuel	PJ	352	374	387	472	602	718
Gaseous Fuel	PJ	0	17	17	17	17	17
ELC.	PJ	0	0	0	0	0	0
Total	PJ	1383	1527	1725	1912	2239	2604
Forecast/1995	1995=1.00	1.00	1.10	1.25	1.38	1.62	1.88
GDP Value	Billion Yuan	246	461	676	1016	1459	2095
PEC[1)] per unit GDP	PJ per Billion Yuan	5.6	3.3	2.6	1.9	1.5	1.2

1): PEC = Primary Energy Consumption

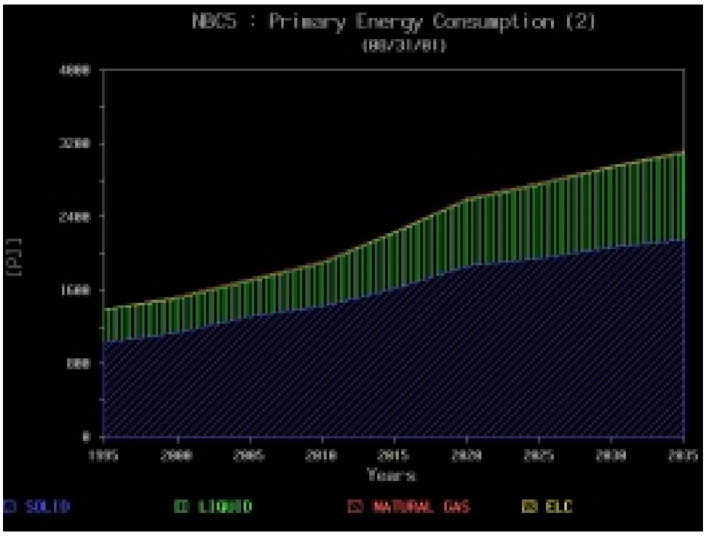

图 7.2: *一次能源消费量*

Figure 7.2: *Primary Energy Consumption*

As shown in Figure 7.3 and Figure 7.4, even with situation of economic structure adjustment from conventional industrial activity to commercial or services, if no further energy and environmental policies, coal will still remains the dominating primary energy in the future of Shanghai. Coal will be used for power generation, iron and steel making, and industrial and commercial boilers for heating.

[3] C:\My Documents\Chen Changhong\美国 EPA 项目\能源与健康\英文报告\第二阶段英文报告\Shanghai_MARKAL_Emission 情景(修改_01).xls

[4] MARKAL: PRIMARY5

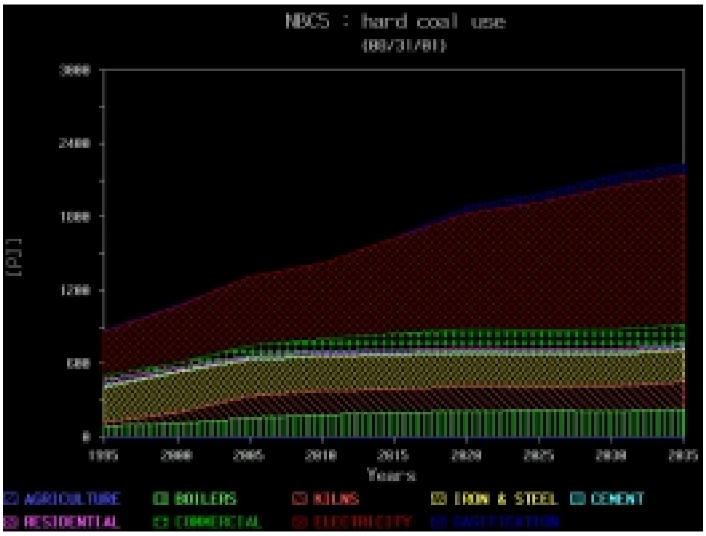

图 7.3: *未来煤炭利用*

Figure 7.3: *Coal Users in Future*

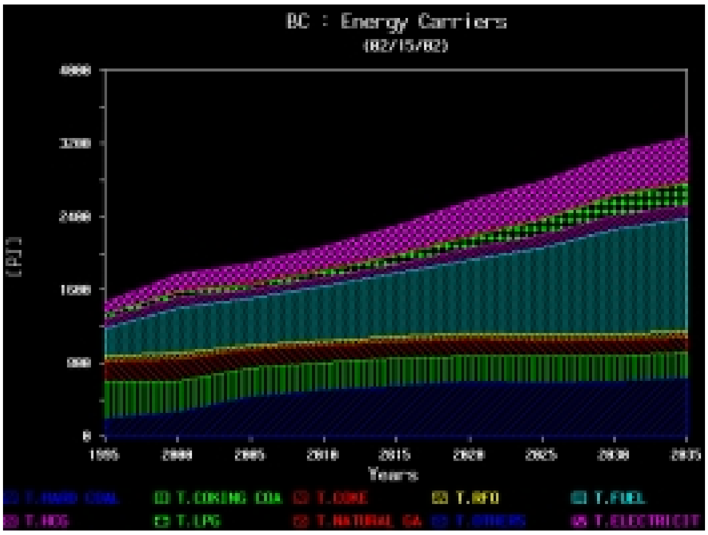

图 7.4: *未来能源消费量及品种*

Figure 7.4: *Energy Consumption by Different Energy Carries*

7.3.3 CO_2 and Local Air Pollutant Emissions from Energy Reference System

As shown in table 7.4-7.7, CO_2 and local air pollutant emission from energy reference system will be increased with the total primary consumption. Compared to 1995, CO_2 emission from energy reference system will increase to 230 Mt in 2020, being 1.91 times of the base year 1995. The major CO_2 emitters are power plant, industry and commercial, the emission contribution from these three sectors are accounted for 40%, 30% and 9%, respectively.

SO_2 emission from energy reference system will be increased from 500 kt in 1995 to 957 kt in 2020, being 1.91 times of the base year 1995. SO_2 emission from power plant, industry, and commercial are accounted for 58%, 26% and 12% of the total emission. The others are less than 5%.

Due to fast growth vehicle population, NOx emission from energy reference system will be increased from 372 kt in 1995 to 848 kt in 2020, being 2.28 times of the base year 1995. The emission contribution from power plant, industry, commercial and transportation will be accounted to 34%, 17%, 14%, and 29% in 2020. Compared to other sectors, the NOx emission from transportation in 2020 is to be 3.09 times of the base year, the emission growth is much faster than power plant, industry and commercials.

PM_{10} emission from fossil fuel burning will be folded in 2020 compared to 1995. The PM_{10} emission contribution from power plant, industry, commercial and transportation sectors in 2020 will be accounted to 36%, 30%, 9% and 16%, respectively. The emission increase ratio of power plant from 1995 to 2020 will be 2.4 times of its base year, industry will be 1.3 times, commercial will be 4.9 times, and transportation is to be 5.2 times.

表 7.4: *能源参照系统的 CO_2 排放量 [百万吨]*

Table 7.4: *CO_2 Emission from Energy Reference System [Mt]*

	1995	2000	2005	2010	2015	2020
POWER PLANTS	36	44	55	61	76	92
INDUSTRY	66	68	68	70	69	70
TRANSPORTATION	5	7	8	12	16	20
AGRICALTURE	1	2	2	3	3	3
COMMERCIAL	3	4	8	11	15	21
RESIDENTIAL	6	6	7	7	8	8
BUNKERS	4	5	9	11	13	16
TOTAL	120	136	156	174	200	230
Forecast/1995	1.00	1.13	1.29	1.44	1.66	1.91

表 7.5: *能源参照系统的 SO_2 排放量 [千吨]*

Table 7.5: *SO_2 Emission from Energy Reference System [kt]*

	1995	2000	2005	2010	2015	2020
POWER PLANTS	281	217	331	362	455	552
INDUSTRY	151	185	216	233	233	246
TRANSPORTATION	1	1	2	4	5	6
AGRICULTURE	4	10	12	14	17	20
COMMERCIAL	27	31	56	76	103	114
RESIDENTIAL	37	20	19	19	19	18
TOTAL	500	463	637	707	831	957
Forecast/1995	1.00	0.93	1.27	1.41	1.66	1.91

表 7.6: *能源参照系统的 NOx 排放量* *[千吨]*

Table 7.6: *NOx Emission from Energy Reference System [kt]*

	1995	2000	2005	2010	2015	2020
POWER PLANTS	155	167	183	205	249	290
INDUSTRY	98	99	120	128	142	147
TRANSPORTATION	80	91	127	166	205	247
AGRICULTURE	3	7	10	12	15	19
COMMERCIAL	19	23	42	57	81	119
RESIDENTIAL	17	17	21	23	24	25
TOTAL	372	405	502	591	717	848
Forecast/1995	1.00	1.09	1.35	1.59	1.93	2.28

表 7.7: *能源参照系统的 PM_{10} 排放量* *[千吨]*

Table 7.7: *PM_{10} Emission from Energy Reference System [kt]*

ROWLABEL	1995	2000	2005	2010	2015	2020
POWER PLANTS	36.8	42.4	49.7	54.2	70.2	88.4
INDUSTRY	56.9	56.5	61.1	65.3	69.9	73.7
TRANSPORTATION	7.5	7.8	18.3	25.7	32.0	38.7
AGRICULTURE	4.9	9.2	11.1	13.1	15.4	17.9
COMMERCIAL	4.3	4.8	8.8	12.2	16.9	20.9
RESIDENTIAL	5.1	3.2	3.4	3.5	3.7	3.8
TOTAL	115.3	123.8	152.3	174.0	208.1	243.3
Forecast/1995	1.00	1.07	1.32	1.51	1.80	2.11

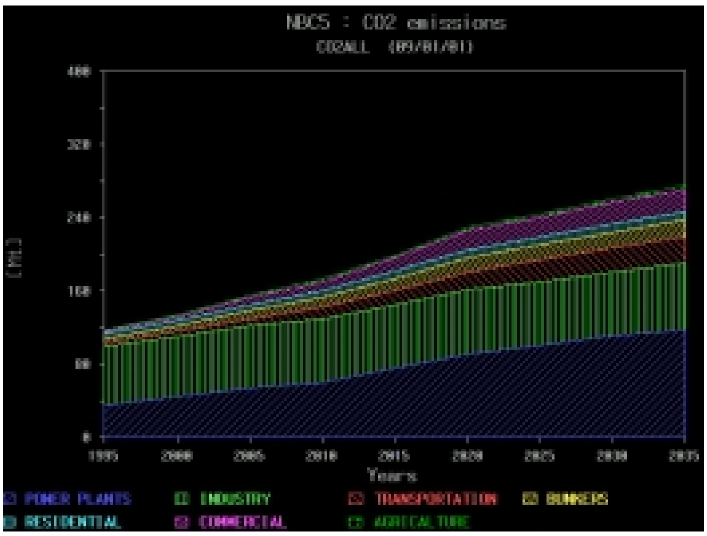

Figure 7.4(a): *CO_2 Emission from Energy Reference System*

图 7.4(a): *能源参照系统的 CO_2 排放量*

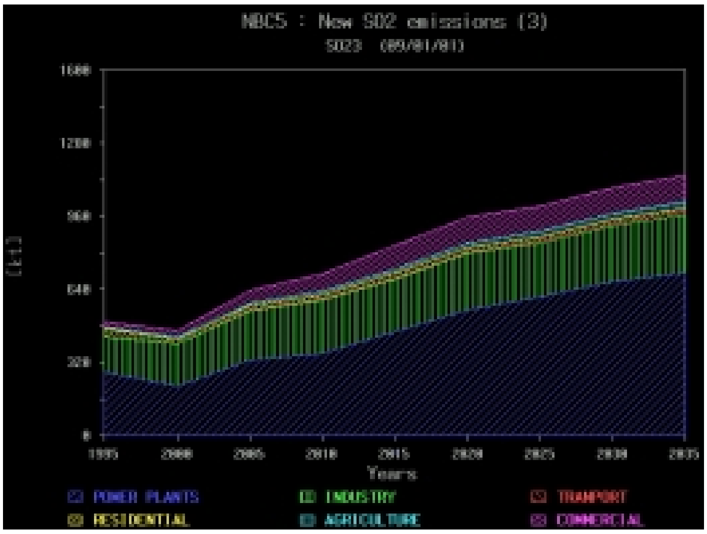

Figure 7.4(b): *SO_2 Emission from Energy Reference System*

图 7.4(b): *能源参照系统的 SO_2 排放量*

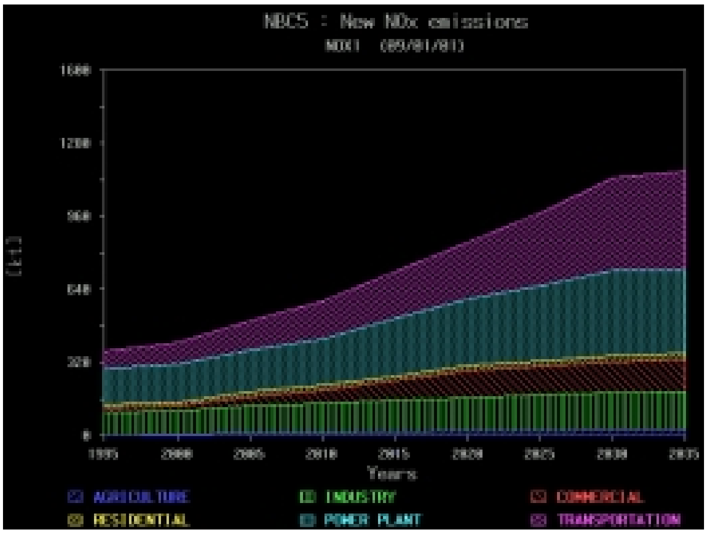

Figure 7.4(c): *NOx Emission from Energy Reference System*

图 7.4(c): *能源参照系统的 NOx 排放量*

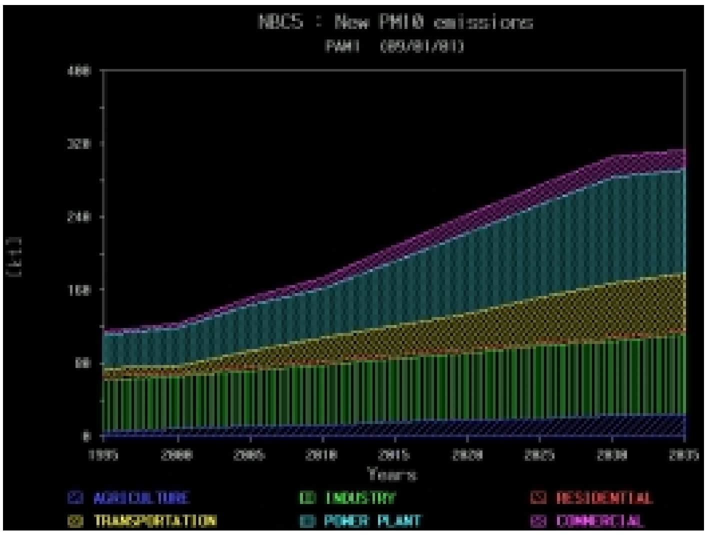

Figure 7.4(d): *PM_{10} Emission from Energy Reference System*

图 7.4(d): *能源参照系统的 PM_{10} 排放量*

7.4 Future Energy and Environmental Policy

7.4.1 Future Policies

In order to reduce air pollutant emission and to improve local air quality in Shanghai, Shanghai municipality drafted a plan for sustainable development, including energy and environmental policies (China's Agenda 21 – Shanghai's Plan of Action, Shanghai municipality 1999). As it is described in the plan, the major problems in the current energy system are as follows:

(1) Total energy use is increasing at a fast rate. Since 1990, the total energy consumption in Shanghai increased at an annual average rate of 5.7%. Coal-based primary energy structure results 35% of the total amount of goods handled at Shanghai's port, exerting great pressures on the transportation system in the city;
(2) The proportion of coal in the total primary energy is becoming larger and larger, reach 66% in 1990 and 70% in 1997, bringing tremendous pressures on the environment;
(3) At present, the utilization rate of energy in Shanghai is less than 40%, which is higher the national average, but still much lower than advanced level.

The major purpose of this plan is to strengthen comprehensive energy planning, develop and adopt advanced energy saving technologies and promote rational and more efficient utilization of energy while developing green energies and renewable energies so as to achieve sustainable development in future.

The options of plan related to energy consumption and sustainable development are:

(1) The total coal consumption in Shanghai will be controlled below 50 million tons by 2005, and 48-50 million tons by 2010. The proportion of coal in primary energy will drop to less than 55%;
(2) The total capacity of coal fired power in the city will be controlled less than 12 GW, and further electricity demand will be supplied by introducing hydro-power from the Three Gorges Project and Qinshan Nuclear Power Station.
(3) The share of natural gas in primary energy will reach 10-12% by 2010 through importing 3-4 billion cubic meters natural gas from Western China by 2005 and 5-6 million tons of liquefied natural gas (LNG) by 2010; This gas will be used for power generation, industrial, commercial and residential use by substituting coal use, and gradually replace the hard coal gas and coke oven gas;
(4) The construction of new coal-fired boilers in the city center will be prohibited. As a matter of principle, no more coal-fired boilers will be built in city-level industrial development zones;
(5) In order to improve energy efficiency, boilers, kilns and furnaces will be renovated. Co-generation is to be promoted in areas where annual load reaches 4000 hours. Gas air-conditioners, solar boilers and passive solar energy will be promoted;
(6) Following up the requirement of the Ten-Fifth Plan of China's Social Economic Development (promulgated on 15 March, 2001), the total SO_2 emission in Shanghai should be reduced 20% on the base year 2000. The SO_2 emission onward 2005 will be targeted at 372 kt per year.

Since there was no targets for NOx and PM_{10} emission reductions, the simulation of NOx and PM10 emission control is just based on a scientific way to evaluate the response of the energy systems when emission targets is settled.

Table 7.8 shows the characteristics of the future energy and environmental policies, and the constraints of Shanghai MARKAL.

表 7.8: *未来能源与环境政策的特点*

Table 7.8: *Characteristics of Future Energy and Environmental Policies*

No.	Future Energy and Environmental Policies	Indicators
1	Limit total coal consumption in Shanghai	Less than 50 Mt, 2000 onward
2	Limit total capacity of coal fired power generation	Less than 12 GW, 2000 onward
3	Import Natural Gas from Western China	3-4 Billion Cubic Meter per year starting at 2003 (117-156 PJ)
4	Import Electricity from 3 Gorges Project	3 GW, 2010 onward
5	Import Electricity from Qinshan Nuclear Power Station	0.3 GW 2010 0.65 GW 2015
6	Import LNG	5-6 million tons 2010 onward
7	Built wind turbine	0.06 GW, 2005 0.30 GW, 2015 0.60 GW, 2035
8	Reducing 20% SO2 Emission by 2005 on base year 2000	400 kt, 2005 onward

7.4.2 Definition of MARKAL Scenarios

As shown in Table 7.9, the modeling scenarios was classified into the following three categories with one reference scenario:

(1) Energy option;
(2) Environmental targets; and
(3) Carbon emission control.

The detail definition of the scenarios was shown in Table 7.10.

表 7.9: *MARKAL 模型运行的情景*

Table 7.9: *Scenario runs in MARKAL*

Model run	Acronym	Economic Growth	Energy Eff. Impr.	Maximum Coal use	Electricity imports	Gas Availability	SO_2 Emission Constraint	NO_x Emission Constraint	PM_{10} Emission Constraint	CO_2 Tax
Base case	BC	X								
Energy Option	EFF	X	X							
	GAS1	X	X	X	X	X				
	GAS2	X	X	X	X	X				
SO2 Emission Target	SO_2	X	X	X	X	X	X			
NOx Emission Target	NOx	X	X	X	X	X	X	X		
PM10 Emission Target	PM_{10}	X	X	X	X	X	X	X	X	
CO2 Tax 1	CO2_1	X	X	X	X	X	X			X
CO2 Tax 2	CO2_2	X	X	X	X	X	X	X		X
CO2 Tax 3	CO2_3	X	X	X	X	X	X	X	X	X

表 7.10: *情景的定义*

Table 7.10: *Definition of Scenario*

No.	Name of scenario	Definition of Scenario
1	BC:	Base Case Scenario
2	EFF:	Energy Efficiency Improvement
3	EFF+GAS1	EFF+Energy Switch at Supply Side
4	EFF+ GAS1+GAS2	EFF+GAS1+Expanding Gas Use
5	EFF+ GAS1+GAS2+SO2	EFF+ GAS1+GAS2+SO2 Emission Control Target
6	EFF+GAS1+GAS2+SO2+NOx 1	EFF+GAS1+GAS2+SO2+NOx Emission Control Target for Transportation Sector
7	EFF+GAS1+GAS2+SO2+NOx 2	EFF+GAS1+GAS2+SO2+NOx Emission Control Target for All Sectors
8	EFF+ GAS1+GAS2+SO2+NOx2+PM10	EFF+ GAS1+GAS2+SO2+NOx+PM10 Emission Control Target
9	EFF+ GAS1+GAS2+SO2+ CO2 200	EFF+ GAS1+GAS2+SO2+CO2 Tax with 200 Yuan/t CO2
10	EFF+ GAS1+GAS2+SO2+ NOx 1 + CO2 200	EFF+ GAS1+GAS2+SO2+NOx 1 + CO2 Tax with 200 Yuan/t CO2
11	EFF+ GAS1+GAS2+SO2+ NOx 2 + CO2 200	EFF+ GAS1+GAS2+SO2+NOx 2 + CO2 Tax with 200 Yuan/t CO2
12	EFF+ GAS1+GAS2+SO2+NOx+PM10 +CO2 200	EFF+ GAS1+GAS2+SO2+NOx+PM10+CO2 Tax with 200 Yuan/t CO2

The base case scenario is the reference case shown in Chapter 7.3.

In the energy option scenario, it consists three sub-components; e.g. energy efficiency improvement (EFF), energy switch at supply side (GAS1), and energy switch at demand side (GAS2). In the energy efficiency improvement scenario, an average of 5-10% was assumed to be improved for the coal use facility from 1995 to 2020. In the GAS1 scenarios, natural gas from Western China was supplied and it was allocated by free market, which depends on least cost of energy system. As gas price is normally higher than coal, the energy demand sector will not willingly select gas to substitute coal. Therefor, the scenario of energy switch at demand side (GAS2) is the local energy and environment policy, which simulates the emission reductions by substituting coal to gas. In this scenario, it was assumed that 35% of coal consumed by end-use sectors substituted by gas in 2005 and 90% in 2035.

The environmental target scenario includes SO_2, NOx and PM_{10} emission control targets. The SO_2 emission target reflects the situation of the local environmental policy to be carried onward 2001. Considering the NOx and PM_{10} pollution Shanghai faced at this moment, NOx and PM_{10} emission control target was set from scientific point of view in the NOx and PM_{10} scenarios for evaluation the response of energy system. Because the emission height of the mobile source is low, its impact on air quality and human health is more seriously than the non-mobile sources, the emission of NOx and PM_{10} was set individually for mobile and non-mobile sources. The detail emission targets set in model were shown in Table 7.11.

表 7.11: *假设的大气污染物排放控制目标[千吨/年]*

Table 7.11: *Assumed Local Air Pollutant Emission Control Target [kt/yr.]*

Local Air Pollutant Emission Control Targets	2005	2020	2035
SO2 Emission Control Target	< 400	< 400	< 400
NOx Emission Control Targets	430	325	325
NOx1 Emission Control Target for Transportation Sector	61	25	25
NOx2 Emission Control Target for All Sectors	391	325	325
PM10 Emission Control Targets	107	73.5	73.5
PM10 Emission Control Target for Mobile Source	7	3.5	3.5
PM10 Emission Control Target for Non-Mobile Source	100	70	70

In order to evaluate the response of the energy system, CO_2 emission tax with 200 Yuan per ton CO_2 was added individually onward SO_2, NOx, and PM_{10} scenarios. The case CO2_1 was SO_2 emission control target + 200 Yuan per ton CO_2, CO2_2 was SO2+NOx emission control target + 200 Yuan per CO_2, and CO2_3 was SO2+NOx+PM10 emission control target + 200 Yuan per CO_2.

表 7.12: *假设的 CO_2 排放控制情景*

Table 7.12: *Assumed Carbon Emission Control Scenarios*

Local Air Pollutant Emission Control Targets	unit	2005	2015	2020
CO2_1: SO2 Emission Control Target+CO2 Tax				
SO2 Emission Control Target	kt	<400	<400	<400
CO2 Tax	Yuan/t		200	200
CO2_2: SO2+NOx Emission Control Targets+CO2 Tax				
SO2 Emission Control Target	kt	<400	<400	<400
NOx1 Emission Control Target	kt	61		25
NOx2 Emission Control Target	kt	391		325
CO2 Tax	Yuan/t		200	200
CO2_3: SO2+NOx+PM10 Emission Control Targets+CO2 Tax				
SO2 Emission Control Target	kt	<400	<400	<400
NOx1 Emission Control Target	kt	61		25
NOx2 Emission Control Target	kt	391		325
PM10 Emission Control Target	kt	107		73.5
CO2 Tax	Yuan/t		200	200

7.5 Scenario Analysis of Shanghai Energy System

7.5.1 Energy Efficiency Improvement Scenario

Table 7.13 and Figure 7.5 shows the primary energy consumption of system in base case and EFF scenario. The results present that if no more gas import, energy efficiency improvement of coal used facilities could only produce 7% of total primary energy consumption. There two reason for situation. One is the average energy efficiency in Shanghai is higher than the one in China. The other is if no more gas import, it is hard for higher efficiency technology to be used, such as gas-fired boilers, gas absorption heat pump, and etc.

表 7.13: *BC 和 EFF 情景下一次能源消费总量的比较*

Table 7.13: *Comparison of Total Primary Energy Consumption[5] of BC and EFF Scenario*

Case	Primary Energy	Unit	1995	2000	2005	2010	2015	2020
BC	Solid Fuel	PJ	1032	1136	1321	1423	1620	1869
	Liquid Fuel	PJ	352	374	387	472	602	718
	Gaseous Fuel	PJ	0	17	17	17	17	17
	ELC.	PJ	0	0	0	0	0	0
	Total	PJ	1383	1527	1725	1912	2239	2604
EFF	Solid Fuel	PJ	1032	1104	1261	1351	1526	1752
	Liquid Fuel	PJ	352	362	387	449	565	664
	Gaseous Fuel	PJ	0	15	17	16	16	15
	ELC.	PJ	0	0	0	0	0	0
	Total	PJ	1383	1480	1664	1816	2107	2431
BC/EFF	Solid Fuel		1.00	0.97	0.95	0.95	0.94	0.94
	Liquid Fuel		1.00	0.97	1.00	0.95	0.94	0.92
	Gaseous Fuel		1.00	0.86	0.98	0.95	0.92	0.91
	ELC.							
	Total		1.00	0.97	0.96	0.95	0.94	0.93

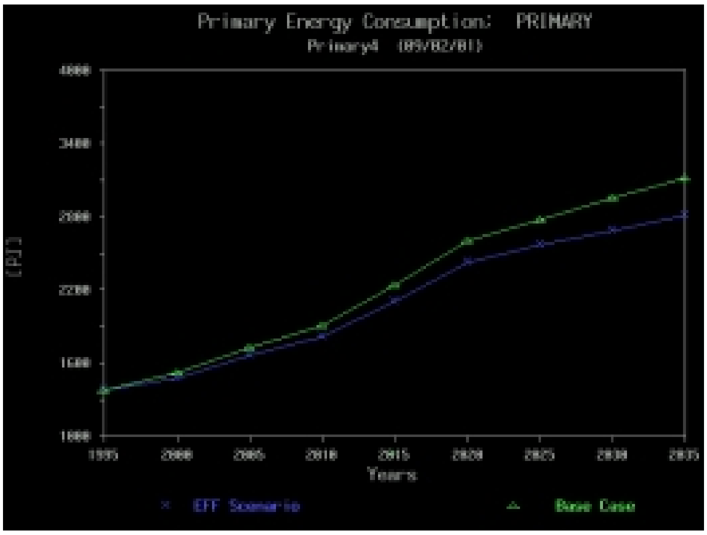

Figure 7.5: *Comparison of Total Primary Energy Consumption of BC and EFF*

图 7.5: *BC 和 EFF 情景下的一次能源消费总量*

Table 7.14 shows even with 5-7% of energy efficiency improvement of coal used facility, it could produce 6 Mt of CO_2 emission reduction in 2005 and 14 Mt reduction in 2020. The share of CO_2 emission of power plant, industry, and transportation in 2020 will be 42%, 30% and 8%.

[5] MARKAL: PRIMARY5

表 7.14: *BC 和 EFF 情景下 CO_2 排放量的比较 [百万吨]*

Table 7.14: *CO_2 Emission[6] of BC and EFF Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
BC	POWER PLANTS	36	44	55	61	76	92
	INDUSTRY	66	68	68	70	69	70
	TRANSPORTATION	5	7	8	12	16	20
	OTHERS	14	17	25	31	39	49
	TOTAL	120	136	156	174	200	230
EFF	POWER PLANTS	36	44	54	60	74	90
	INDUSTRY	66	65	64	65	64	64
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	24	30	36	45
	TOTAL	120	133	150	165	188	216
EFF/BC	POWER PLANTS	1.00	0.99	0.99	0.98	0.97	0.98
	INDUSTRY	1.00	0.97	0.94	0.93	0.93	0.91
	TRANSPORTATION	1.00	1.00	0.96	0.93	0.90	0.88
	OTHERS	1.00	0.97	0.96	0.94	0.93	0.92
	TOTAL	1.00	0.98	0.97	0.95	0.94	0.94

With the energy efficiency improvement, SO_2 emission from industry and other final sectors will reduce 35 kt and 21 kt in 2020, being 14% and 13% reduction of each total emission compared with base case. As coal consumption for power generation increases, the emission reduction of power plant can be neglected, as shown in Table 7.15. However, the emission reduction of NOx and PM_{10} can be neglected.

表 7.15(a): *BC 和 EFF 情景下 SO_2 排放量的比较 [千吨]*

Table 7.15(a): *SO_2 Emission[7] of BC and EFF Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
BC	POWER PLANTS	281	217	331	362	455	552
	INDUSTRY	151	185	216	233	233	246
	OTHERS	69	61	90	113	143	159
	TOTAL	500	463	637	707	831	957
EFF	POWER PLANTS	281	216	329	355	443	539
	INDUSTRY	151	170	191	202	203	211
	OTHERS	69	58	83	103	125	138
	TOTAL	500	445	603	660	771	888
EFF/BC	POWER PLANTS	1.00	0.99	0.99	0.98	0.97	0.98
	INDUSTRY	1.00	0.92	0.88	0.87	0.87	0.86
	OTHERS	1.00	0.96	0.93	0.91	0.87	0.87
	TOTAL	1.00	0.96	0.95	0.93	0.93	0.93

[6] MARKAL: CO24

[7] MARKAL: SO24

表 7.15(b): *BC 和 EFF 情景下 NOx 排放量的比较 [千吨]*

Table 7.15(b): *NOx Emission[8] of BC and EFF Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
BC	POWER PLANTS	155	167	183	205	249	290
	INDUSTRY	98	99	120	128	142	147
	TRANSPORTATION	80	91	127	166	205	247
	OTHERS	39	48	72	92	121	163
	TOTAL	372	405	502	591	717	848
EFF	POWER PLANTS	155	166	185	201	243	300
	INDUSTRY	98	100	119	127	142	147
	TRANSPORTATION	80	91	120	163	200	240
	OTHERS	39	46	69	86	111	149
	TOTAL	372	403	492	577	696	836
EFF/BC	POWER PLANTS	1.00	0.99	1.01	0.98	0.97	1.03
	INDUSTRY	1.00	1.00	0.99	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	0.95	0.98	0.98	0.97
	OTHERS	1.00	0.96	0.95	0.94	0.92	0.91
	TOTAL	1.00	0.99	0.98	0.98	0.97	0.99

表 7.15(c): *BC 和 EFF 情景下 PM_{10} 排放量的比较 [千吨]*

Table 7.15(c): *PM_{10} Emission[9] of BC and EFF Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
BC	POWER PLANTS	37	42	50	54	70	88
	INDUSTRY	57	57	61	65	70	74
	TRANSPORTATION	8	8	18	26	32	39
	OTHERS	14	17	23	29	36	43
	TOTAL	115	124	152	174	208	243
EFF	POWER PLANTS	37	42	49	53	68	83
	INDUSTRY	57	57	60	65	70	74
	TRANSPORTATION	8	8	18	25	32	38
	OTHERS	14	15	20	25	30	35
	TOTAL	115	122	148	168	200	230
EFF/BC	POWER PLANTS	1.00	0.99	0.99	0.98	0.97	0.94
	INDUSTRY	1.00	1.00	0.98	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	0.97	0.99	0.99	0.99
	OTHERS	1.00	0.90	0.88	0.86	0.84	0.83
	TOTAL	1.00	0.98	0.97	0.97	0.96	0.95

7.5.2 Gas Supply Scenario

This scenario implies CO_2 and local air pollutant emission from energy system when coal is bounded 50 million tons onward 2005, and import gas from Western China, import electricity from the Three Gorges project and Qinshan Nuclear Power Station.

As shown in Figure 7.6, natural gas and electricity is to be appeared in the GAS1 scenario, as "new primary energy carriers". As natural gas imported, it makes possible for some energy technology with higher efficiency, e.g. gas-fired power generation, to be adopted in the energy conversion process. And due to hydro-power imported, total coal consumption of the system will

[8] MARKAL: NOx4

[9] MARKAL: PAM6

be greatly reduced onward 2005. As shown in Table 7.16, the total primary energy consumption will be reduced 10% in 2020 compared with EFF case.

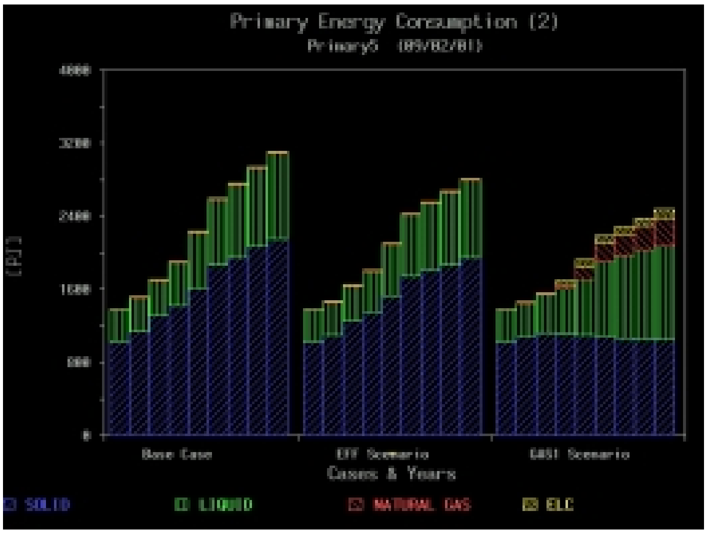

Figure 7.6: *Comparison of Total Primary Energy Consumption of BC, EFF and GAS1*

图 7.6: *BC、EFF 和 GAS1 情景下的一次能源消费总量*

表 7.16: *BC、EFF 和 GAS1 情景下一次能源消费总量的比较*

Table 7.16: *Total Primary Energy Consumption of EFF and GAS1 Scenario*

Case	Primary Energy	Unit	1995	2000	2005	2010	2015	2020
EFF	Solid Fuel	PJ	1032	1104	1261	1351	1526	1752
	Liquid Fuel	PJ	352	362	387	449	565	664
	Gaseous Fuel	PJ	0	15	17	16	16	15
	ELC.	PJ	0	0	0	0	0	0
	Total	PJ	1383	1480	1664	1816	2107	2431
GAS1	Solid Fuel	PJ	1032	1097	1124	1111	1098	1086
	Liquid Fuel	PJ	352	362	427	495	619	817
	Gaseous Fuel	PJ	0	15	17	53	135	211
	ELC.	PJ	0	0	9	47	75	82
	Total	PJ	1383	1474	1576	1705	1927	2197
GAS1/EFF	Solid Fuel		1.00	0.99	0.89	0.82	0.72	0.62
	Liquid Fuel		1.00	1.00	1.10	1.10	1.10	1.23
	Gaseous Fuel		1.00	1.00	1.02	3.26	8.62	13.71
	Total		1.00	1.00	0.95	0.94	0.91	0.90

With the import of gas and electricity onward 2005 and higher energy efficiency technology adopted, the CO_2 emission from the energy system will reduce 39 Mt in 2020, being 18% of the total of EFF case.

The SO_2 and PM_{10} emission from the energy system will reduce 314 kt and 47 kt, being 35% and 20% reduction on the base of EFF case, as shown in Table 7.18. Most of reduction is to be achieved by power plants through adopting gas-fired power generation. The share of SO2 and PM_{10} from power plant in 2020 will be decreased from 61% and 36% in EFF case to 45% and 21%. The total NOx emission from energy system will reduce 142 kt in 2020, being 17% of total of EFF case.

表 7.17: *EFF 和 GAS1 情景下 CO_2 排放量的比较 [百万吨]*

Table 7.17: *CO_2 Emission of GAS1 and EFF Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
EFF	POWER PLANTS	36	44	54	60	74	90
	INDUSTRY	66	65	64	65	64	64
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	24	30	36	45
	TOTAL	120	133	150	165	188	216
GAS1	POWER PLANTS	36	44	47	45	47	55
	INDUSTRY	66	64	62	62	61	62
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	24	30	36	44
	TOTAL	120	132	141	148	159	177
GAS1/EFF	POWER PLANTS	1.00	1.00	0.87	0.76	0.64	0.61
	INDUSTRY	1.00	0.98	0.96	0.95	0.95	0.96
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.01	1.01	1.01	0.97
	TOTAL	1.00	0.99	0.94	0.89	0.84	0.82

表 7.18(a): *EFF 和 GAS1 情景下 SO_2 排放量的比较 [千吨]*

Table 7.18(a): *SO_2 Emission of GAS1 and EFF Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
EFF	POWER PLANTS	281	216	329	355	443	539
	INDUSTRY	151	170	191	202	203	211
	OTHERS	69	58	83	103	125	138
	TOTAL	500	445	603	660	771	888
GAS1	POWER PLANTS	281	216	269	255	238	256
	INDUSTRY	151	170	191	203	203	211
	OTHERS	69	58	85	104	127	106
	TOTAL	500	445	545	562	568	574
GAS1/EFF	POWER PLANTS	1.00	1.00	0.82	0.72	0.54	0.48
	INDUSTRY	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.02	1.02	1.02	0.77
	TOTAL	1.00	1.00	0.90	0.85	0.74	0.65

表 7.18(b): *EFF 和 GAS1 情景下 NOx 排放量的比较 [千吨]*

Table 7.18(b): *NOx Emission of GAS1 and EFF Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
EFF	POWER PLANTS	155	166	185	201	243	300
	INDUSTRY	98	100	119	127	142	147
	TRANSPORTATION	80	91	120	163	200	240
	OTHERS	39	46	69	86	111	149
	TOTAL	372	403	492	577	696	836
GAS1	POWER PLANTS	155	166	148	142	145	174
	INDUSTRY	98	100	116	121	134	139
	TRANSPORTATION	80	91	119	163	200	239
	OTHERS	39	46	69	87	112	143
	TOTAL	372	403	453	513	592	694
GAS1/EFF	POWER PLANTS	1.00	1.00	0.80	0.71	0.60	0.58
	INDUSTRY	1.00	1.00	0.98	0.95	0.95	0.94
	TRANSPORTATION	1.00	1.00	0.99	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.01	1.01	1.01	0.96
	TOTAL	1.00	1.00	0.92	0.89	0.85	0.83

表 7.18(c): *EFF 和 GAS1 情景下 PM_{10} 排放量的比较 [千吨]*

Table 7.18(c): *PM_{10} Emission of GAS1 and EFF Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
EFF	POWER PLANTS	37	42	49	53	68	83
	INDUSTRY	57	57	60	65	70	74
	TRANSPORTATION	8	8	18	25	32	38
	OTHERS	14	15	20	25	30	35
	TOTAL	115	122	148	168	200	230
GAS1	POWER PLANTS	37	42	40	37	36	39
	INDUSTRY	57	56	57	59	63	66
	TRANSPORTATION	8	8	18	25	32	38
	OTHERS	14	15	21	26	31	41
	TOTAL	115	121	136	147	161	183
GAS1/EFF	POWER PLANTS	1.00	1.00	0.81	0.70	0.52	0.47
	INDUSTRY	1.00	0.99	0.95	0.91	0.90	0.89
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.05	1.03	1.03	1.16
	TOTAL	1.00	1.00	0.92	0.88	0.81	0.80

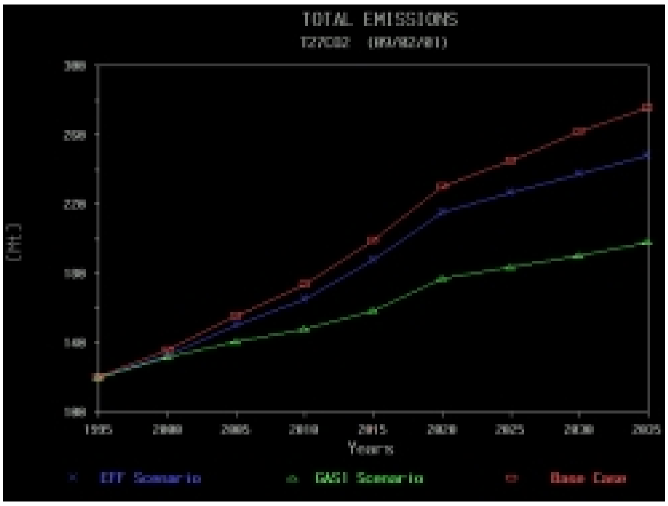

Figure 7.7(a): *CO_2 Emission of BC, EFF and GAS1*

图 7.7(a): *EFF 和 GAS1 情景下的 CO_2 排放量*

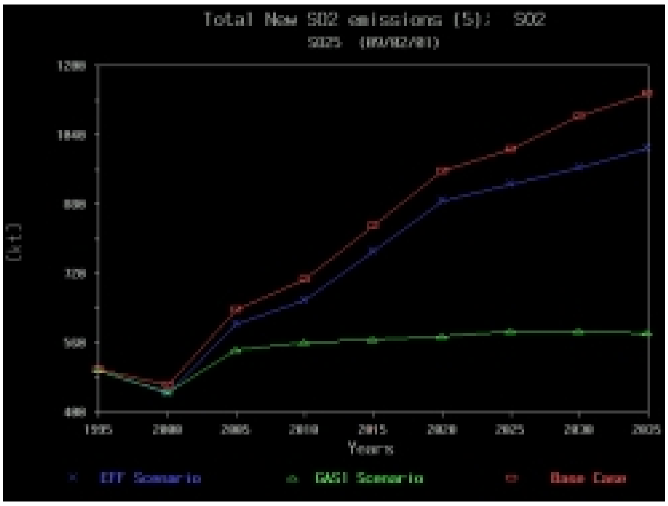

Figure 7.7(b): *SO_2 Emission of BC, EFF and GAS1*

图 7.7(b): *EFF 和 GAS1 情景下的 SO_2 排放量*

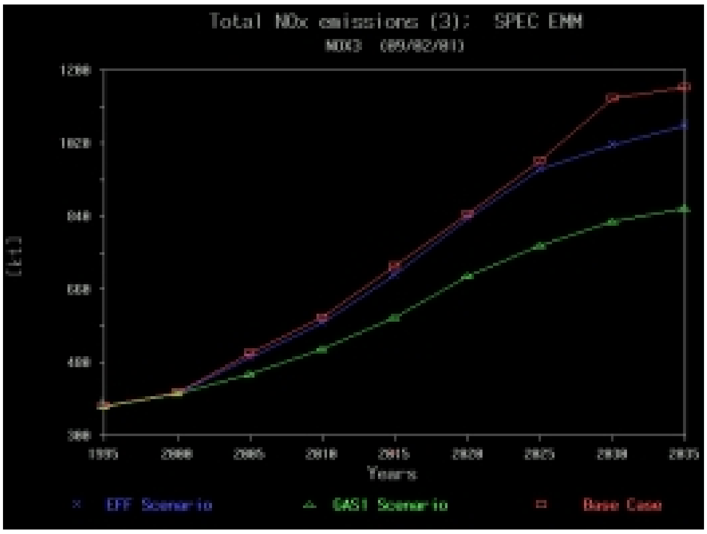

Figure 7.7(c): *NOx Emission of BC, EFF and GAS1*
图 7.7(c): *EFF 和 GAS1 情景下的 NOx 排放量*

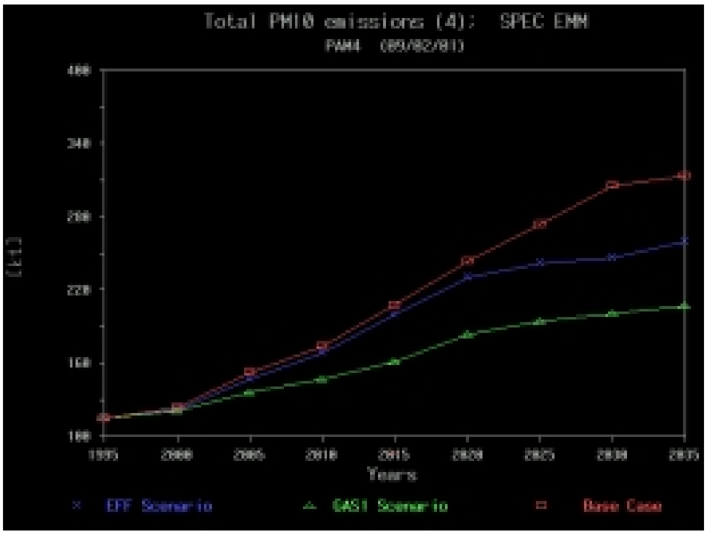

Figure 7.7(d): *PM_{10} Emission of BC, EFF and GAS1*
图 7.7(d): *EFF 和 GAS1 情景下的 PM_{10} 排放量*

7.5.3 Expanding Gas Use Scenario

Table 7.19-7.21 shows the changes of primary energy consumption and emissions when expand gas use for final sectors. From the Tables, we can see when expanding gas for final use, there is no big difference of total coal consumption between GAS2 and GAS1 scenarios. However, the total liquid fuel will be reduced 20%.

表 7.19: *GAS1 和 GAS2 情景下一次能源消费量的比较*

Table 7.19: *Total Primary Energy Consumption of GAS2 and GAS1 Scenario*

Case	Primary Energy	Unit	1995	2000	2005	2010	2015	2020
GAS1	Solid Fuel	PJ	1032	1097	1124	1111	1098	1086
	Liquid Fuel	PJ	352	362	427	495	619	817
	Gaseous Fuel	PJ	0	15	17	53	135	211
	ELC.	PJ	0	0	9	47	75	82
	Total	PJ	1383	1474	1576	1705	1927	2197
GAS2	Solid Fuel	PJ	1032	1105	1119	1099	1100	1055
	Liquid Fuel	PJ	352	362	382	440	560	652
	Gaseous Fuel	PJ	0	15	132	181	249	413
	ELC.	PJ	0	0	9	47	75	82
	Total	PJ	1383	1482	1641	1767	1984	2202
GAS2/GAS1	Solid Fuel		1.00	1.01	1.00	0.99	1.00	0.97
	Liquid Fuel		1.00	1.00	0.90	0.89	0.90	0.80
	Gaseous Fuel		1.00	1.00	7.75	3.45	1.85	1.95
	Total		1.00	1.01	1.04	1.04	1.03	1.00

With the expanding gas use for final energy demand sectors, more coal would be used for power generations as coal use reduced at final sectors. The CO_2 emission from power plant would be increased by 10% compared to GAS1 scenario. And CO_2 emission from industry and other sectors would totally reduce 10 Mt in 2020, being 10% of reductions.

Though CO_2 emission reduction is limited when expanding the gas use for final energy demand sectors, the SO_2 and PM_{10} emission of the energy system would notably reduce 110 kt and 24 kt in 2020, being 19% and 13% reduction onward GAS1. And NOx emission from energy system would be slightly increased. The big increase would be happened in power generations as its coal consumption increased.

表 7.20: *GAS2 和 GAS1 情景下上海市 CO_2 排放量的比较 [Mt]*

Table 7.20: *CO_2 Emission of GAS2 and GAS1 Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS1	POWER PLANTS	36	44	47	45	47	55
	INDUSTRY	66	64	62	62	61	62
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	24	30	36	44
	TOTAL	120	132	141	148	159	177
GAS2	POWER PLANTS	36	44	53	52	57	60
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	22	27	32	40
	TOTAL	120	133	144	149	162	174
GAS2/GAS1	POWER PLANTS	1.00	1.00	1.12	1.15	1.21	1.10
	INDUSTRY	1.00	1.02	0.98	0.96	0.95	0.91
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	0.92	0.91	0.88	0.93
	TOTAL	1.00	1.01	1.02	1.01	1.02	0.98

表 7.21(a): *GAS2 和 GAS1 情景下上海市 SO_2 排放量的比较 [kt]*

Table 7.21(a): *SO_2 Emission of GAS2 and GAS1 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS1	POWER PLANTS	281	216	269	255	238	256
	INDUSTRY	151	170	191	203	203	211
	OTHERS	69	58	85	104	127	106
	TOTAL	500	445	545	562	568	574
GAS2	POWER PLANTS	281	216	320	316	339	327
	INDUSTRY	151	171	132	124	110	95
	OTHERS	69	58	51	47	44	43
	TOTAL	500	445	503	486	493	464
GAS2/GAS1	POWER PLANTS	1.00	1.00	1.19	1.24	1.42	1.27
	INDUSTRY	1.00	1.00	0.69	0.61	0.54	0.45
	OTHERS	1.00	1.00	0.60	0.45	0.35	0.40
	TOTAL	1.00	1.00	0.92	0.87	0.87	0.81

表 7.21(b): *GAS2 和 GAS1 情景下上海市 NOx 排放量的比较 [kt]*

Table 7.21(b): *NOx Emission of GAS2 and GAS1 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS1	POWER PLANTS	155	166	148	142	145	174
	INDUSTRY	98	100	116	121	134	139
	TRANSPORTATION	80	91	119	163	200	239
	OTHERS	39	46	69	87	112	143
	TOTAL	372	403	453	513	592	694
GAS2	POWER PLANTS	155	166	178	173	189	197
	INDUSTRY	98	100	118	123	133	135
	TRANSPORTATION	80	91	121	161	201	242
	OTHERS	39	46	65	84	110	155
	TOTAL	372	403	482	540	633	729
GAS2/GAS1	POWER PLANTS	1.00	1.00	1.20	1.21	1.30	1.14
	INDUSTRY	1.00	1.00	1.01	1.02	0.99	0.98
	TRANSPORTATION	1.00	1.00	1.01	0.99	1.00	1.01
	OTHERS	1.00	1.00	0.94	0.96	0.98	1.09
	TOTAL	1.00	1.00	1.06	1.05	1.07	1.05

表 7.21(c): *GAS2 和 GAS1 情景下上海市 PM_{10} 排放量的比较 [kt]*

Table 7.21(c): *PM_{10} Emission of GAS2 and GAS1 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS1	POWER PLANTS	37	42	40	37	36	39
	INDUSTRY	57	56	57	59	63	66
	TRANSPORTATION	8	8	18	25	32	38
	OTHERS	14	15	21	26	31	41
	TOTAL	115	121	136	147	161	183
GAS2	POWER PLANTS	37	42	48	47	50	48
	INDUSTRY	57	52	50	51	52	51
	TRANSPORTATION	8	8	18	25	32	38
	OTHERS	14	15	16	17	19	21
	TOTAL	115	118	132	140	153	159
GAS2/GAS1	POWER PLANTS	1.00	1.00	1.19	1.25	1.40	1.24
	INDUSTRY	1.00	0.94	0.88	0.87	0.82	0.78
	TRANSPORTATION	1.00	1.00	1.01	0.99	1.00	1.01
	OTHERS	1.00	1.00	0.75	0.66	0.62	0.51
	TOTAL	1.00	0.97	0.97	0.95	0.95	0.87

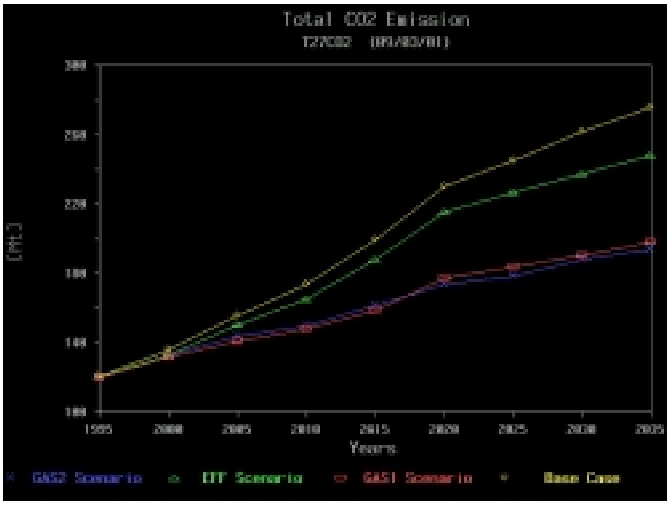

Figure 7.8(a): *CO_2 Emission of BC, EFF, GAS1 and GAS2*

图 7.8(a): *BC, EFF,GAS1 和 GAS2 情景下上海市 CO_2 排放量*

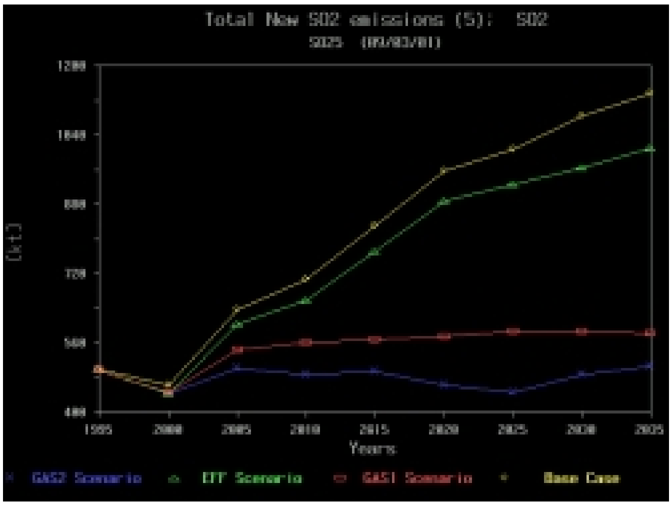

Figure 7.8(b): *SO_2 Emission of BC, EFF, GAS1 and GAS2*

图 7.8(b): *BC, EFF,GAS1 和 GAS2 情景下上海市 SO_2 排放量*

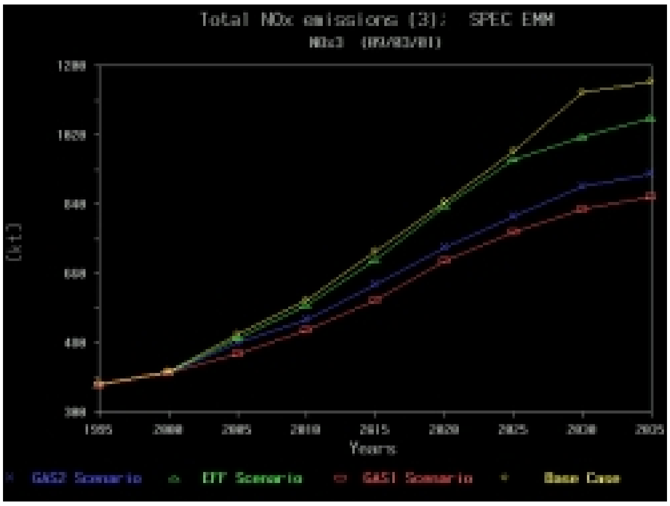

Figure 7.8(c): *NOx Emission of BC, EFF, GAS1 and GAS2*

图 7.8(c): *BC, EFF,GAS1 和 GAS2 情景下上海市 NOx 排放量*

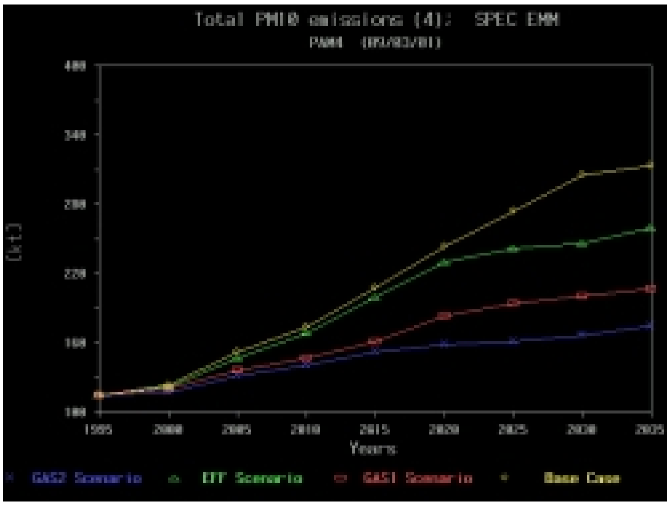

Figure 7.8(d): *PM_{10} Emission of BC, EFF, GAS1 and GAS2*

图 7.8(d): *BC, EFF,GAS1 和 GAS2 情景下上海市 PM_{10} 排放量*

7.5.4 SO_2 Emission Target Scenario

SO_2 Emission target scenario is a realistic policy to be carried out in the next five years. As described in the scenario definition section of this report, Shanghai has to reduce its SO_2 emission by 20% on the base 2000. According to the simulation results of Shanghai MARKAL model, the total amount of SO_2 emission in Shanghai by 2000 was 463 kt in energy reference system. The model results are very close to 465 kt, the statistic from Shanghai Environmental Protection Bureau. Therefor, the total SO_2 emission in Shanghai by 2005 must be less than 372 kt. Considering some projects approved before 2000 and to be constructed after 2000, the total SO_2 emission target was set to be 400 kt.

If SO_2 emission control policy is to be implemented, the end-pipe technology, e.g. desupherization, must be installed in power plant. To meet the SO_2 emission target, a capacity of 1.67 GW coal fired power generation for desupherization must be achieved. As shown in Table 7.23, with the gas expanding, the total SO_2 emission from Shanghai energy system will be declined continually onward 2005. And co-benefit of this policy on CO_2, NOx and PM_{10} emission reduction can be almost negligible.

表 7.22: *GAS2 和 SO2 情景下上海市 CO_2 排放量的比较 [Mt]*

Table 7.22: *CO_2 Emission of SO2 and GAS2 Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS2	POWER PLANTS	36	44	53	52	57	60
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	22	27	32	40
	TOTAL	120	133	144	149	162	174
SO2	POWER PLANTS	36	44	45	45	49	57
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	23	28	33	41
	TOTAL	120	133	137	143	155	172
SO2/GAS2	POWER PLANTS	1.00	1.00	0.85	0.85	0.86	0.96
	INDUSTRY	1.00	1.00	1.01	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.04	1.04	1.04	1.01
	TOTAL	1.00	1.00	0.96	0.96	0.96	0.99

表 7.23(a): *GAS2 和 SO2 情景下上海市 SO_2 排放量的比较 [kt]*

Table 7.23(a): *SO_2 Emission of SO2 and GAS2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS2	POWER PLANTS	281	216	320	316	339	327
	INDUSTRY	151	171	132	124	110	95
	OTHERS	69	58	51	47	44	43
	TOTAL	500	445	503	486	493	464
SO2	POWER PLANTS	281	216	187	187	187	187
	INDUSTRY	151	171	132	124	110	95
	OTHERS	69	58	53	49	47	46
	TOTAL	500	445	372	360	344	328
SO2/GAS2	POWER PLANTS	1.00	1.00	0.58	0.59	0.55	0.57
	INDUSTRY	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.05	1.06	1.07	1.08
	TOTAL	1.00	1.00	0.74	0.74	0.70	0.71

表 7.23(b): *GAS2 和 SO2 情景下上海市 NOx 排放量的比较 [kt]*

Table 7.23(b): *NOx Emission of SO2 and GAS2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS2	POWER PLANTS	155	166	178	173	189	197
	INDUSTRY	98	100	118	123	133	135
	TRANSPORTATION	80	91	121	161	201	242
	OTHERS	39	46	65	84	110	155
	TOTAL	372	403	482	540	633	729
SO2	POWER PLANTS	155	166	136	140	155	190
	INDUSTRY	98	100	120	123	133	135
	TRANSPORTATION	80	91	121	161	199	240
	OTHERS	39	46	70	89	117	158
	TOTAL	372	403	447	514	604	723
SO2/GAS2	POWER PLANTS	1.00	1.00	0.77	0.81	0.82	0.96
	INDUSTRY	1.00	1.00	1.02	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	1.00	1.00	0.99	0.99
	OTHERS	1.00	1.00	1.08	1.07	1.06	1.02
	TOTAL	1.00	1.00	0.93	0.95	0.95	0.99

表 7.23(c): *GAS2 和 SO2 情景下上海市 PM_{10} 排放量的比较 [kt]*

Table 7.23(c): *PM_{10} Emission of SO2 and GAS2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
GAS2	POWER PLANTS	37	42	48	47	50	48
	INDUSTRY	57	52	50	51	52	51
	TRANSPORTATION	8	8	18	25	32	38
	OTHERS	14	15	16	17	19	21
	TOTAL	115	118	132	140	153	159
SO2	POWER PLANTS	37	42	38	38	40	45
	INDUSTRY	57	52	52	52	52	51
	TRANSPORTATION	8	8	18	25	31	38
	OTHERS	14	15	18	19	21	22
	TOTAL	115	118	126	134	144	157
SO2/GAS2	POWER PLANTS	1.00	1.00	0.79	0.81	0.80	0.94
	INDUSTRY	1.00	1.00	1.04	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	1.00	1.00	0.99	1.00
	OTHERS	1.00	1.00	1.12	1.13	1.08	1.07
	TOTAL	1.00	1.00	0.95	0.95	0.94	0.99

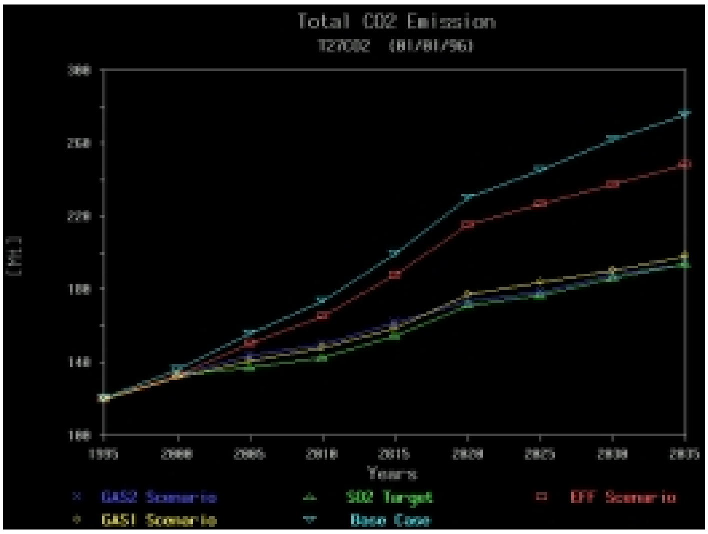

Figure 7.9(a): *CO_2 Emission of BC, EFF, GAS1, GAS2 and SO2 Scenario*

图 7.9(a): *BC, EFF,GAS1, GAS2 和 SO2 情景下上海市 CO_2 排放量*

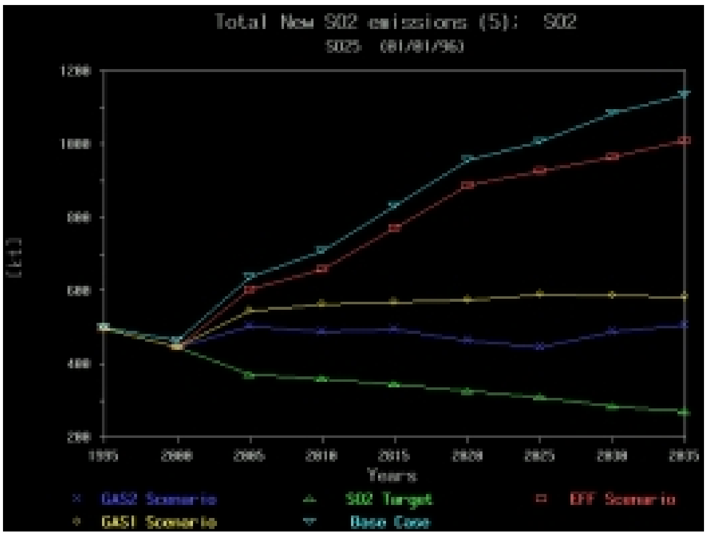

Figure 7.9(b): *SO_2 Emission of BC, EFF, GAS1, GAS2 and SO2 Scenario*

图 7.9(b): *BC, EFF,GAS1, GAS2 和 SO2 情景下上海市 SO_2 排放量*

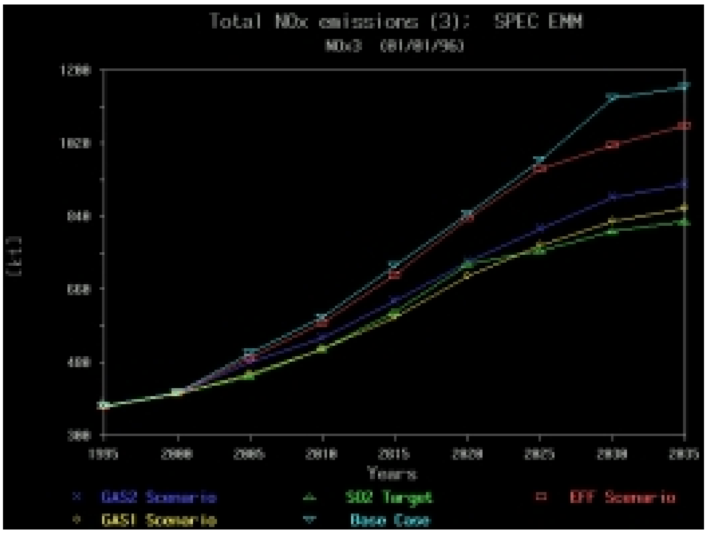

Figure 7.9(c): *NOx Emission of BC, EFF, GAS1, GAS2 and SO2 Scenario*
图 7.9(c): *BC, EFF,GAS1, GAS2 和 SO2 情景下上海市 NOx 排放量*

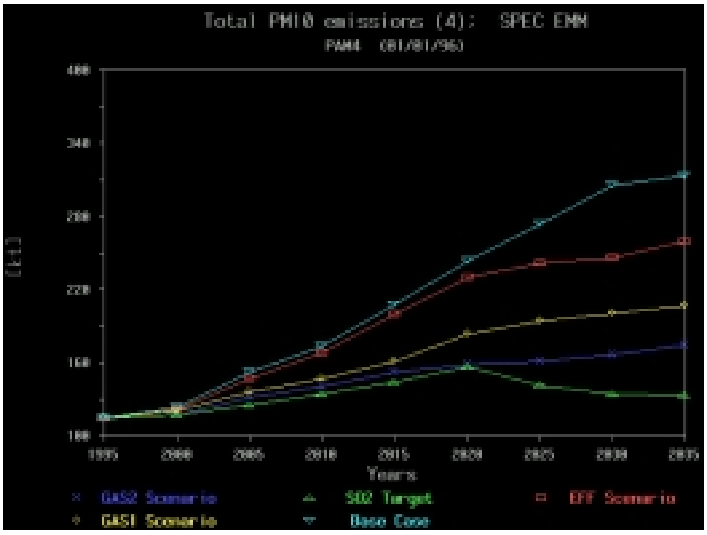

Figure 7.9(d): *PM_{10} Emission of BC, EFF, GAS1, GAS2 and SO2 Scenario*
图 7.9(d): *BC, EFF,GAS1, GAS2 和 SO2 情景下上海市 PM_{10} 排放量*

7.5.5 NOx Emission Target Scenario

NOx emission target scenario reflects the response of the energy system when an utmost target settled for NOx emission. In this scenario, the NOx emission target for mobile and non-mobile sources is bounded 25 kt and 300 kt per year onward 2020, respectively.

With this utmost target, a more stringent emission standards, e.g. EURO II before 2005, EURO III before 2010, and EURO IV before 2015, must be implemented for new vehicles in Shanghai, and vehicle inspection and maintenance program must be carried out. The NOx emission from transportation will be declined from 723 kt in SO2 emission target scenario to 325 kt in NOx emission target scenario in 2020, shown in Table 7.25.

According to the Ten-fifth plan for Shanghai Air Quality Protection latterly prepared (Shanghai EPB, September 2001), the implementation of EURO II for new vehicles in 2003 or 2004 is under consideration. Vehicle inspection and maintenance for in-use vehicle will be happened in 2005. Following this option, the fuel quality will be improved. The sulfur content in gasoline will be reduced from 1000 ppm to 200 ppm in 2005, and 30 ppm in 2010. The sulfur content in diesel will be reduced from 3000 ppm to 300 ppm in 2005, and 30 ppm in 2010.

With the target for non-mobile sources, power generation will introduce select catalytic reactor (SCR) to achieve maximum reduction on NOx.

The model result shows the co-benefit of this option could produce 41% of PM_{10} emission reduction and 4% of SO_2 emission reduction onward SO_2 emission target scenario, shown in Table 7.25.

表 7.24: *NOx 和 SO2 情景下上海市 CO_2 排放量的比较 [Mt]*

Table 7.24: *CO_2 Emission of NOx and SO2 Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	36	44	45	45	49	57
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	23	28	33	41
	TOTAL	120	133	137	143	155	172
NOx1	POWER PLANTS	36	44	46	45	49	58
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	12	15	14
	OTHERS	14	17	23	28	33	47
	TOTAL	120	133	139	144	156	175
NOx2	POWER PLANTS	36	44	44	43	48	61
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	12	15	14
	OTHERS	14	17	23	28	32	41
	TOTAL	120	133	136	142	153	173
NOx1/SO2	POWER PLANTS	1.00	1.00	1.02	1.02	1.00	1.01
	INDUSTRY	1.00	1.00	1.00	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	1.05	1.06	1.08	0.80
	OTHERS	1.00	1.00	1.00	1.00	1.00	1.15
	TOTAL	1.00	1.00	1.01	1.01	1.01	1.02
NOx2/SO2	POWER PLANTS	1.00	1.00	0.97	0.97	0.97	1.07
	INDUSTRY	1.00	1.00	1.00	1.00	1.00	0.99
	TRANSPORTATION	1.00	1.00	1.05	1.06	1.06	0.82
	OTHERS	1.00	1.00	1.01	0.98	0.97	1.01
	TOTAL	1.00	1.00	0.99	0.99	0.99	1.01

表 7.25(a): *NOx 和 SO2 情景下上海市 SO_2 排放量的比较 [kt]*

Table 7.25(a): *SO_2 Emission of NOx and SO2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	281	216	187	187	187	187
	INDUSTRY	151	171	132	124	110	95
	OTHERS	69	58	53	49	47	46
	TOTAL	500	445	372	360	344	328
NOx1	POWER PLANTS	281	216	187	187	187	187
	INDUSTRY	151	171	133	124	110	95
	OTHERS	69	58	52	47	44	41
	TOTAL	500	445	372	358	341	323
NOx2	POWER PLANTS	281	213	187	187	187	187
	INDUSTRY	151	171	127	115	99	86
	OTHERS	69	58	52	47	44	41
	TOTAL	500	442	366	349	329	314
NOx1/SO2	POWER PLANTS	1.00	1.00	1.00	1.00	1.00	1.00
	INDUSTRY	1.00	1.00	1.01	1.00	1.00	1.00
	OTHERS	1.00	1.00	0.98	0.96	0.94	0.90
	TOTAL	1.00	1.00	1.00	0.99	0.99	0.99
NOx2/SO2	POWER PLANTS	1.00	0.99	1.00	1.00	1.00	1.00
	INDUSTRY	1.00	1.00	0.96	0.93	0.89	0.90
	OTHERS	1.00	1.00	0.98	0.96	0.94	0.90
	TOTAL	1.00	0.99	0.98	0.97	0.96	0.96

表 7.25(b): *NOx 和 SO2 情景下上海市 NOx 排放量的比较 [kt]*

Table 7.25(b): *NOx Emission of NOx and SO2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	155	166	136	140	155	190
	INDUSTRY	98	100	120	123	133	135
	TRANSPORTATION	80	91	121	161	199	240
	OTHERS	39	46	70	89	117	158
	TOTAL	372	403	447	514	604	723
NOx1	POWER PLANTS	155	166	143	144	158	193
	INDUSTRY	98	100	120	124	133	135
	TRANSPORTATION	80	91	61	63	44	25
	OTHERS	39	46	70	90	117	158
	TOTAL	372	402	394	420	451	511
NOx2	POWER PLANTS	155	165	130	119	81	57
	INDUSTRY	98	100	109	112	116	122
	TRANSPORTATION	80	91	61	63	44	25
	OTHERS	39	46	71	89	112	121
	TOTAL	372	402	370	383	354	325
NOx1/SO2	POWER PLANTS	1.00	1.00	1.05	1.03	1.01	1.02
	INDUSTRY	1.00	1.00	1.00	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	0.50	0.39	0.22	0.10
	OTHERS	1.00	1.00	1.00	1.00	1.00	1.00
	TOTAL	1.00	1.00	0.88	0.82	0.75	0.71
NOx2/SO2	POWER PLANTS	1.00	1.00	0.95	0.86	0.52	0.30
	INDUSTRY	1.00	1.00	0.91	0.91	0.88	0.90
	TRANSPORTATION	1.00	1.00	0.50	0.39	0.22	0.10
	OTHERS	1.00	1.00	1.01	0.99	0.96	0.77
	TOTAL	1.00	1.00	0.83	0.74	0.59	0.45

表 7.25(c): *NOx 和 SO2 情景下上海市 PM_{10} 排放量的比较* *[kt]*

Table 7.25(c): *PM_{10} Emission of NOx and SO2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	37	42	38	38	40	45
	INDUSTRY	57	52	52	52	52	51
	TRANSPORTATION	8	8	18	25	31	38
	OTHERS	14	15	18	19	21	22
	TOTAL	115	118	126	134	144	157
NOx1	POWER PLANTS	37	42	40	39	40	46
	INDUSTRY	57	52	52	52	52	51
	TRANSPORTATION	8	8	10	9	5	5
	OTHERS	14	15	18	19	20	22
	TOTAL	115	118	119	119	118	124
NOx2	POWER PLANTS	37	42	34	32	23	16
	INDUSTRY	57	52	52	52	52	51
	TRANSPORTATION	8	8	10	9	6	5
	OTHERS	14	15	18	19	20	22
	TOTAL	115	118	114	113	101	93
NOx1/SO2	POWER PLANTS	1.00	1.00	1.05	1.04	1.01	1.02
	INDUSTRY	1.00	1.00	1.00	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	0.56	0.37	0.17	0.12
	OTHERS	1.00	1.00	0.98	0.98	0.98	0.99
	TOTAL	1.00	1.00	0.95	0.89	0.82	0.79
NOx2/SO2	POWER PLANTS	1.00	1.00	0.90	0.86	0.59	0.36
	INDUSTRY	1.00	1.00	1.01	1.00	1.00	1.00
	TRANSPORTATION	1.00	1.00	0.56	0.37	0.18	0.12
	OTHERS	1.00	1.00	0.97	1.00	0.98	0.96
	TOTAL	1.00	1.00	0.91	0.84	0.70	0.59

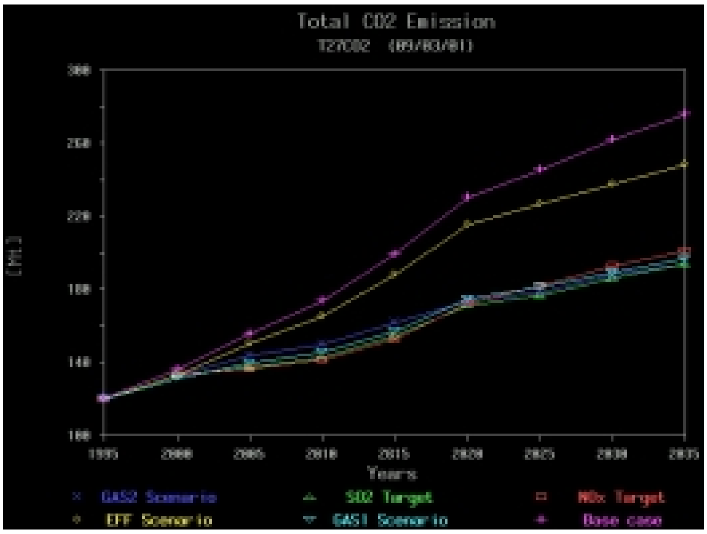

Figure 7.10(a): *CO_2 Emission of BC, EFF, GAS1, GAS2, SO2 and NOx Scenario*

图 7.10(a): *BC, EFF,GAS1, GAS2, SO2 和 NOx 情景下上海市 CO_2 排放量*

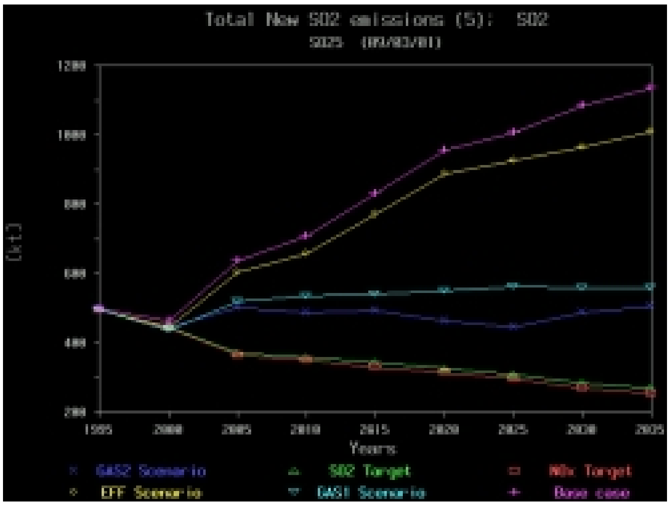

Figure 7.10(b): *SO_2 Emission of BC, EFF, GAS1, GAS2, SO2 and NOx Scenario*

图 7.10(b): *BC, EFF,GAS1, GAS2, SO2 和 NOx 情景下上海市 SO_2 排放量*

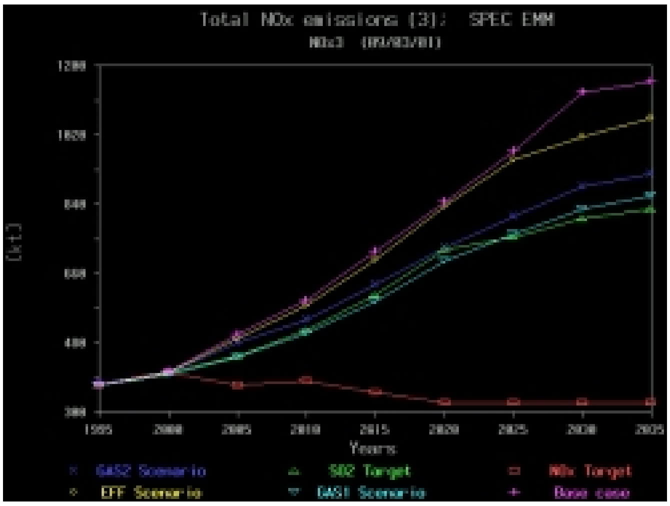

Figure 7.10(c): *NOx Emission of BC, EFF, GAS1, GAS2, SO2 and NOx Scenario*

图 7.10(c): *BC, EFF,GAS1, GAS2, SO2 和 NOx 情景下上海市 NOx 排放量*

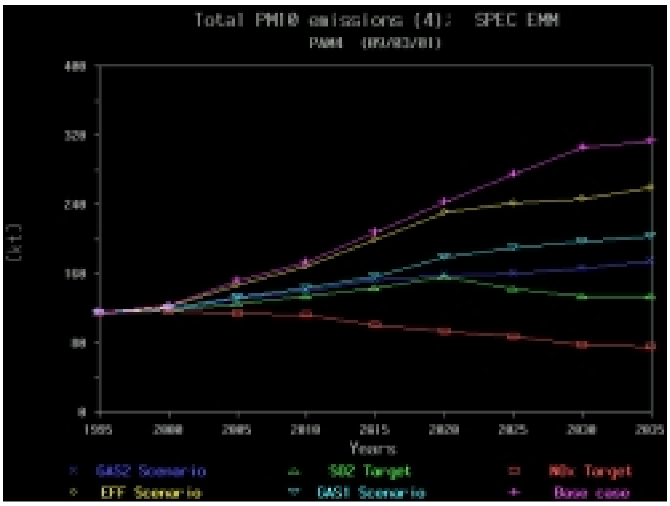

Figure 7.10(d): *PM_{10} Emission of BC, EFF, GAS1, GAS2, SO2 and NOx Scenario*

图 7.10(d): *BC, EFF,GAS1, GAS2, SO2 和 NOx 情景下上海市 PM_{10} 排放量*

7.5.6 PM_{10} Emission Target Scenario

Table 7.25-7.26 shows the model results of CO_2 and local air pollutant emission when PM_{10} emission target adopted.

Following this requirement on PM_{10} emission control target, more USC steam CHP with deesulphurization, SCR and PM removal technology would be introduced in power generation. The total CO_2 emission will be reduced by 6 Mt, being 3% reduction from NOx emission target scenario, while SO_2 and PM_{10} emission will reduce 26% and 21%, respectively.

表 7.25: *PM10 和 NOx 情景下上海市 CO_2 排放量的比较 [Mt]*

Table 7.25: *CO_2 Emission of PM10 and NOx Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	36	44	44	43	48	61
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	12	15	14
	OTHERS	14	17	23	28	32	41
	TOTAL	120	133	136	142	153	173
PM10	POWER PLANTS	36	44	44	45	47	58
	INDUSTRY	66	65	60	57	53	51
	TRANSPORTATION	5	7	8	11	12	14
	OTHERS	14	17	23	29	37	44
	TOTAL	120	133	136	142	148	167
PM10/NOx2	POWER PLANTS	1.00	1.00	1.00	1.05	0.99	0.94
	INDUSTRY	1.00	1.00	0.98	0.95	0.91	0.91
	TRANSPORTATION	1.00	1.02	1.07	0.93	0.79	1.03
	OTHERS	1.00	1.00	1.00	1.06	1.13	1.06
	TOTAL	1.00	1.00	1.00	1.00	0.97	0.97

表 7.26(a): *PM10 和 NOx 情景下上海市 SO_2 排放量的比较 [kt]*

Table 7.26(a): *SO_2 Emission of PM10 and NOx Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	281	213	187	187	187	187
	INDUSTRY	151	171	127	115	99	86
	OTHERS	69	58	52	47	44	41
	TOTAL	500	442	366	349	329	314
PM10	POWER PLANTS	281	212	187	187	150	132
	INDUSTRY	151	171	133	123	110	70
	OTHERS	69	58	52	45	40	31
	TOTAL	500	442	372	355	300	232
PM10/NOx2	POWER PLANTS	1.00	1.00	1.00	1.00	0.80	0.70
	INDUSTRY	1.00	1.00	1.05	1.07	1.11	0.82
	OTHERS	1.00	1.00	0.99	0.94	0.92	0.75
	TOTAL	1.00	1.00	1.02	1.01	0.91	0.74

表 7.26(b): *PM10 和 NOx 情景下上海市 NOx 排放量的比较 [kt]*

Table 7.26(b): *NOx Emission of PM10 and NOx Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	155	165	130	119	81	57
	INDUSTRY	98	100	109	112	116	122
	TRANSPORTATION	80	91	61	63	44	25
	OTHERS	39	46	71	89	112	121
	TOTAL	372	402	370	383	354	325
PM10	POWER PLANTS	155	165	107	94	65	33
	INDUSTRY	98	100	115	122	132	122
	TRANSPORTATION	80	89	40	36	43	25
	OTHERS	39	46	71	88	114	145
	TOTAL	372	399	332	340	353	325
PM10/NOx2	POWER PLANTS	1.00	1.00	0.83	0.78	0.79	0.59
	INDUSTRY	1.00	1.00	1.05	1.09	1.13	1.00
	TRANSPORTATION	1.00	0.98	0.65	0.58	0.99	1.00
	OTHERS	1.00	1.00	1.00	0.99	1.01	1.19
	TOTAL	1.00	0.99	0.90	0.89	1.00	1.00

表 7.26(c): *PM10 和 NOx 情景下上海市 PM_{10} 排放量的比较 [kt]*

Table 7.26(c): *PM_{10} Emission of PM10 and NOx Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	37	42	34	32	23	16
	INDUSTRY	57	52	52	52	52	51
	TRANSPORTATION	8	8	10	9	6	5
	OTHERS	14	15	18	19	20	22
	TOTAL	115	118	114	113	101	93
PM10	POWER PLANTS	37	42	28	25	17	8
	INDUSTRY	57	52	50	48	45	44
	TRANSPORTATION	8	6	7	6	5	4
	OTHERS	14	15	17	17	18	19
	TOTAL	115	116	102	96	85	74
PM10/NOx2	POWER PLANTS	1.00	1.00	0.82	0.77	0.71	0.48
	INDUSTRY	1.00	1.00	0.95	0.92	0.87	0.85
	TRANSPORTATION	1.00	0.82	0.71	0.62	0.84	0.76
	OTHERS	1.00	1.00	1.00	0.91	0.90	0.86
	TOTAL	1.00	0.99	0.90	0.85	0.84	0.79

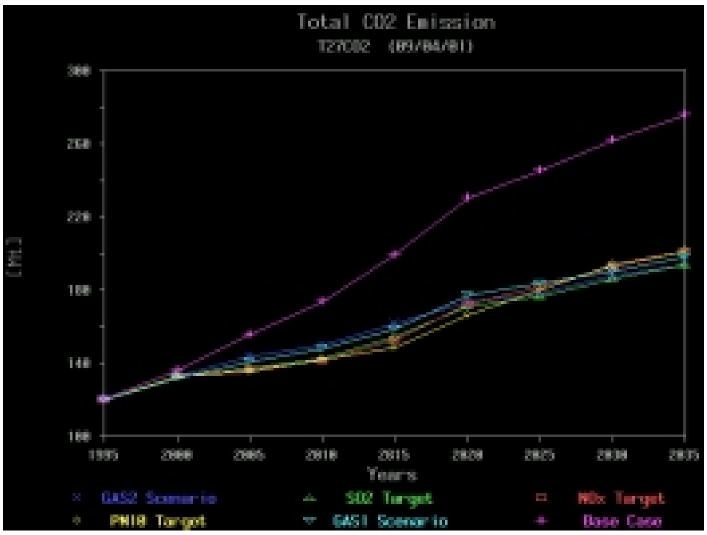

Figure 7.11(a): *CO_2 Emission of BC, GAS1, GAS2, SO2, NOx and PM10 Scenario*

图 7.11(a): *BC, EFF,GAS1, GAS2, SO2, NOx 和 PM10 情景下上海市 CO_2 排放量*

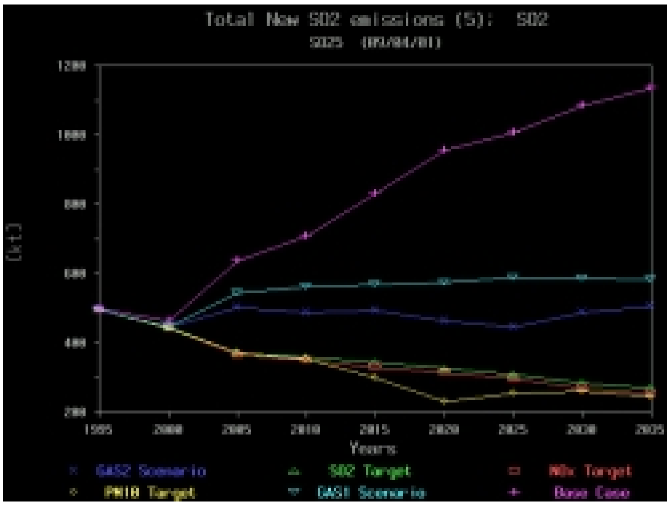

Figure 7.11(b): *SO_2 Emission of BC, GAS1, GAS2, SO2, NOx and PM10 Scenario*

图 7.11(b): *BC, EFF,GAS1, GAS2, SO2, NOx 和 PM10 情景下上海市 SO_2 排放量*

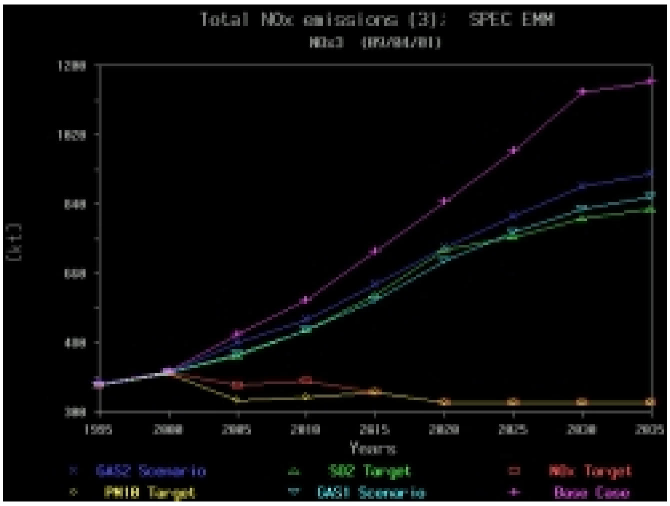

Figure 7.11(c): *NOx Emission of BC, GAS1, GAS2, SO2, NOx and PM10 Scenario*

图 7.11(c): *BC, EFF,GAS1, GAS2, SO2, NOx 和 PM10 情景下上海市 NOx 排放量*

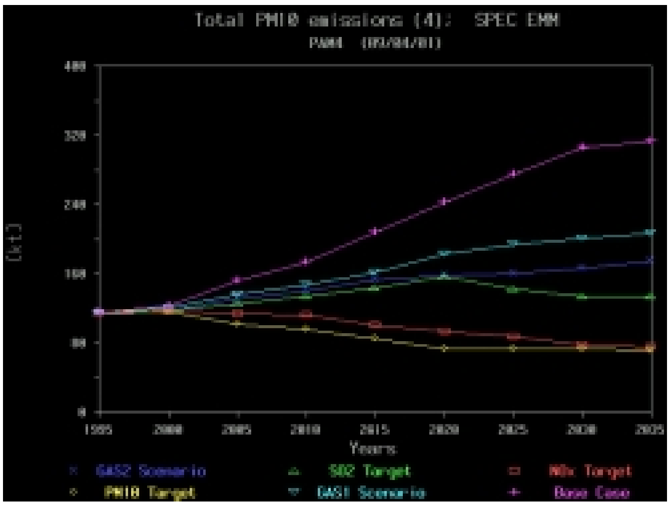

Figure 7.11(d): *PM10 Emission of BC, GAS1, GAS2, SO2, NOx and PM10 Scenario*

图 7.11(d): *BC, EFF,GAS1, GAS2, SO2, NOx 和 PM10 情景下上海市 PM_{10} 排放量*

7.5.7 SO_2 Emission Target + CO2 Tax Scenario

Table 7.27-7.28 and Figure 7.12 shows the CO_2 and local air pollutant emissions from energy system when a tax of 200 Yuan per ton CO_2 was added on the base of SO_2 emission control target scenario.

The model results show the total CO_2 emission will be reduced by 10% in 2020 on base SO_2 target scenario. With this 200 tax, NOx and PM_{10} emission will have 3% and 12% reduction in 2020 and no benefit on SO2 emission reduction. Compared to NOx emission control target and PM_{10} emission control target, the further reduction of NOx and PM_{10} emission is mainly depend on the introduction of end-pipe technologies, e.g. SCR, lower nitrogen burners, three way catalytic converter, PM removals, and etc.

表 7.27: *SO2+CO2 税和 SO2 情景下上海市 CO_2 排放量的比较 [Mt]*

Table 7.27: *CO_2 Emission of SO2+CO2 Tax and SO2 Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	36	44	45	45	49	57
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	23	28	33	41
	TOTAL	120	133	137	143	155	172
SO2+ CO2 Tax	POWER PLANTS	36	44	44	44	46	53
	INDUSTRY	66	64	59	47	47	46
	TRANSPORTATION	5	7	8	11	14	17
	OTHERS	14	17	23	27	32	39
	TOTAL	120	132	134	129	139	155
CO2 Tax/ SO2	POWER PLANTS	1.00	0.99	0.98	0.98	0.95	0.92
	INDUSTRY	1.00	0.98	0.97	0.79	0.80	0.81
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.00	0.97	0.96	0.96
	TOTAL	1.00	0.99	0.98	0.90	0.90	0.90

表 7.28(a): *SO2+CO2 税和 SO2 情景下上海市 SO_2 排放量的比较 [kt]*

Table 7.28(a): *SO_2 Emission of SO2+CO2 Tax and SO2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	281	216	187	187	187	187
	INDUSTRY	151	171	132	124	110	95
	OTHERS	69	58	53	49	47	46
	TOTAL	500	445	372	360	344	328
SO2+ CO2 Tax	POWER PLANTS	281	214	187	187	187	187
	INDUSTRY	151	172	132	124	110	95
	OTHERS	69	58	53	49	47	46
	TOTAL	500	445	372	360	344	328
CO2 Tax/ SO2	POWER PLANTS	1.00	0.99	1.00	1.00	1.00	1.00
	INDUSTRY	1.00	1.01	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.00	1.00	1.00	1.00
	TOTAL	1.00	1.00	1.00	1.00	1.00	1.00

表 7.28(b): *SO2+CO2 税和 SO2 情景下上海市 NOx 排放量的比较 [kt]*

Table 7.28(b): *NOx Emission of SO2+CO2 Tax and SO2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	155	166	136	140	155	190
	INDUSTRY	98	100	120	123	133	135
	TRANSPORTATION	80	91	121	161	199	240
	OTHERS	39	46	70	89	117	158
	TOTAL	372	403	447	514	604	723
SO2+ CO2 Tax	POWER PLANTS	155	164	132	137	145	145
	INDUSTRY	98	100	119	138	148	151
	TRANSPORTATION	80	91	122	161	199	253
	OTHERS	39	46	70	88	114	152
	TOTAL	372	401	443	524	605	702
CO2 Tax/ SO2	POWER PLANTS	1.00	0.99	0.97	0.98	0.93	0.76
	INDUSTRY	1.00	1.00	0.99	1.12	1.11	1.11
	TRANSPORTATION	1.00	1.00	1.01	1.00	1.00	1.06
	OTHERS	1.00	1.00	1.00	0.98	0.97	0.97
	TOTAL	1.00	1.00	0.99	1.02	1.00	0.97

表 7.28(c): *SO2+CO2 税和 SO2 情景下上海市 PM_{10} 排放量的比较 [kt]*

Table 7.28(c): *PM_{10} Emission of SO2+CO2 Tax and SO2 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
SO2	POWER PLANTS	37	42	38	38	40	45
	INDUSTRY	57	52	52	52	52	51
	TRANSPORTATION	8	8	18	25	31	38
	OTHERS	14	15	18	19	21	22
	TOTAL	115	118	126	134	144	157
SO2+ CO2 Tax	POWER PLANTS	37	42	36	37	37	34
	INDUSTRY	57	52	50	43	44	44
	TRANSPORTATION	8	8	18	25	31	33
	OTHERS	14	15	18	19	21	27
	TOTAL	115	117	123	124	133	138
CO2 Tax/ SO2	POWER PLANTS	1.00	0.99	0.95	0.97	0.92	0.75
	INDUSTRY	1.00	0.99	0.97	0.84	0.85	0.86
	TRANSPORTATION	1.00	1.00	1.01	1.00	1.00	0.87
	OTHERS	1.00	1.00	1.02	1.00	1.02	1.20
	TOTAL	1.00	0.99	0.98	0.93	0.93	0.88

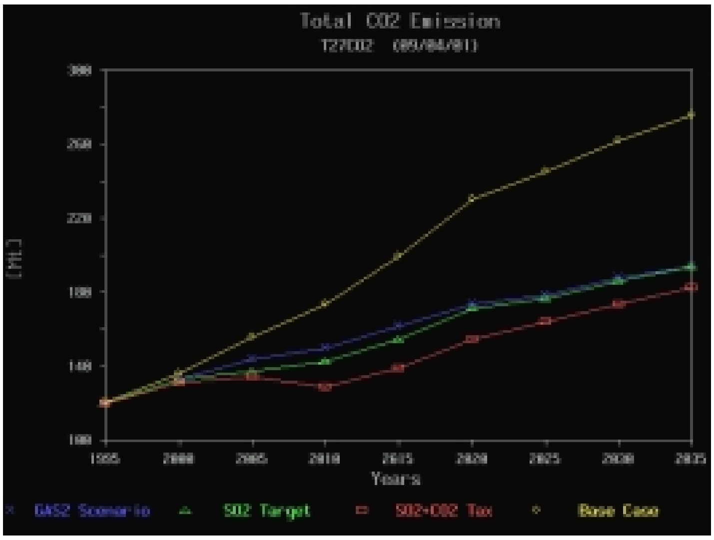

Figure 7.12(a): *CO_2 Emission of BC, GAS2, SO2 and SO2+CO2 Tax Scenario*

图 7.12(a): *BC, GAS2, SO2 和 SO2+CO2 排放税情景下上海市 CO_2 排放量*

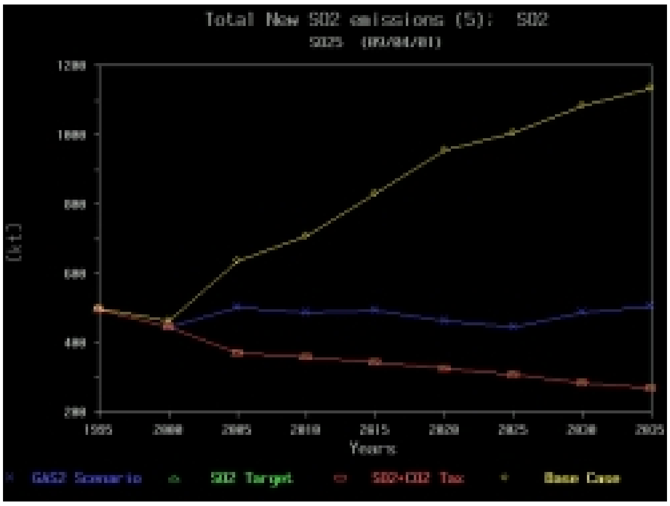

Figure 7.12(b): *SO_2 Emission of BC, GAS2, SO2 and SO2+CO2 Tax Scenario*

图 7.12(b): *BC, GAS2, SO2 和 SO2+CO2 排放税情景下上海市 SO_2 排放量*

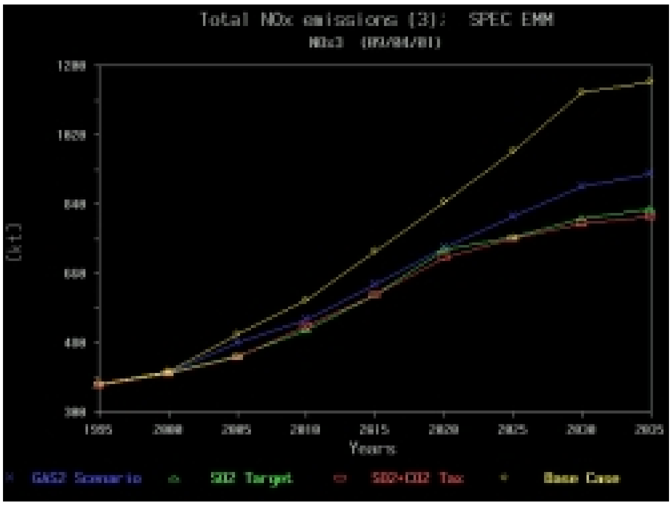

Figure 7.12(c): *NOx Emission of BC, GAS2, SO2 and SO2+CO2 Tax Scenario*

图 7.12(c): *BC, GAS2, SO2 和 SO2+CO2 排放税情景下上海市 NOx 排放量*

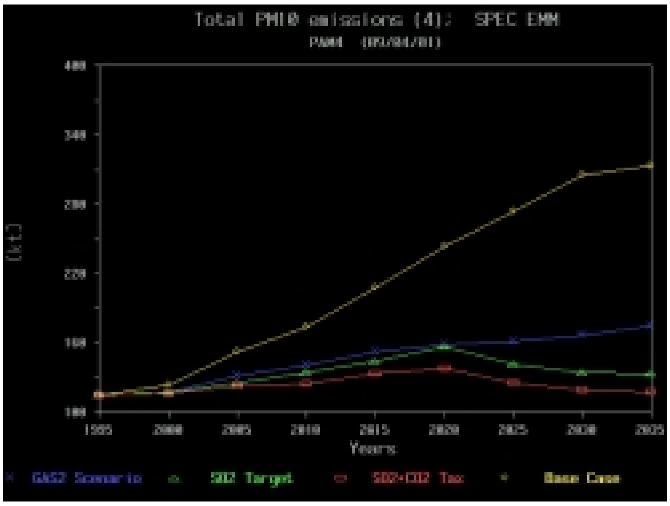

Figure 7.12(d): *PM_{10} Emission of BC, GAS2, SO2 and SO2+CO2 Tax Scenario*

图 7.12(d): *BC, GAS2, SO2 和 SO2+CO2 排放税情景下上海市 PM_{10} 排放量*

7.5.8 SO_2+NOx Emission Target + CO_2 Tax Scenario

Table 7.29-7.30 and Figure 7.13 shows the CO_2 and local air pollutant emissions from energy system when CO_2 tax was added on the base of SO2+NOx emission control targets scenario.

Comparing to NOx emission control target scenario, CO2 emission will have further reduction by 9% in 2020, 5% of SO2 emission reduction, and 14% of PM10 emission reduction on the base of NOx scenario.

表 7.29: *SO2+NOx+CO2 税和 SO2+NOx 情景下上海市 CO_2 排放量的比较* *[Mt]*

Table 7.29: *CO_2 Emission of SO2+NOx+CO2 Tax and NOx Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	36	44	44	43	48	61
	INDUSTRY	66	65	61	59	58	56
	TRANSPORTATION	5	7	8	12	15	14
	OTHERS	14	17	23	28	32	41
	TOTAL	120	133	136	142	153	173
SO2+NOx2+ CO2 Tax	POWER PLANTS	36	44	43	42	44	56
	INDUSTRY	66	64	59	46	46	45
	TRANSPORTATION	5	7	8	12	15	15
	OTHERS	14	17	23	27	32	41
	TOTAL	120	131	133	127	137	157
SO2+NOx2+ CO2 Tax/ NOx2	POWER PLANTS	1.00	0.99	0.99	0.98	0.93	0.92
	INDUSTRY	1.00	0.98	0.96	0.78	0.79	0.81
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.02	1.11
	OTHERS	1.00	1.00	0.99	0.98	0.98	0.98
	TOTAL	1.00	0.99	0.97	0.90	0.90	0.91

表 7.30(a): *SO2+NOx+CO2 税和 SO2+NOx 情景下上海市 SO_2 排放量的比较* *[kt]*

Table 7.30(a): *SO_2 Emission of SO2+NOx+CO2 Tax and NOx Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	281	213	187	187	187	187
	INDUSTRY	151	171	127	115	99	86
	OTHERS	69	58	52	47	44	41
	TOTAL	500	442	366	349	329	314
SO2+NOx2+ CO2 Tax	POWER PLANTS	281	195	187	180	171	143
	INDUSTRY	151	172	122	117	99	84
	OTHERS	69	58	52	47	44	41
	TOTAL	500	425	361	344	314	268
SO2+NOx2+ CO2 Tax/ NOx2	POWER PLANTS	1.00	0.92	1.00	0.96	0.92	0.77
	INDUSTRY	1.00	1.01	0.97	1.02	1.00	0.98
	OTHERS	1.00	1.00	1.00	1.00	1.00	1.00
	TOTAL	1.00	0.96	0.99	0.98	0.95	0.86

表 7.30(b): *SO2+NOx+CO2 税和 SO2+NOx 情景下上海市 NOx 排放量的比较* *[kt]*

Table 7.30(b): *NOx Emission of SO2+NOx+CO2 Tax and NOx Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	155	165	130	119	81	57
	INDUSTRY	98	100	109	112	116	122
	TRANSPORTATION	80	91	61	63	44	25
	OTHERS	39	46	71	89	112	121
	TOTAL	372	402	370	383	354	325
SO2+NOx2+ CO2 Tax	POWER PLANTS	155	160	129	106	68	33
	INDUSTRY	98	100	109	127	129	135
	TRANSPORTATION	80	91	61	63	44	25
	OTHERS	39	46	71	88	113	132
	TOTAL	372	396	370	383	354	325
SO2+NOx2+ CO2 Tax/ NOx2	POWER PLANTS	1.00	0.97	1.00	0.88	0.83	0.59
	INDUSTRY	1.00	1.00	1.00	1.13	1.11	1.11
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.01	0.99	1.01	1.09
	TOTAL	1.00	0.99	1.00	1.00	1.00	1.00

表 7.30(c): *SO2+NOx+CO2 税和 SO2+NOx 情景下上海市 PM_{10} 排放量的比较 [kt]*

Table 7.30(c): *PM_{10} Emission of SO2+NOx+CO2 Tax and NOx Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
NOx2	POWER PLANTS	37	42	34	32	23	16
	INDUSTRY	57	52	52	52	52	51
	TRANSPORTATION	8	8	10	9	6	5
	OTHERS	14	15	18	19	20	22
	TOTAL	115	118	114	113	101	93
SO2+NOx2+ CO2 Tax	POWER PLANTS	37	42	34	30	20	9
	INDUSTRY	57	52	48	41	42	42
	TRANSPORTATION	8	8	10	9	5	5
	OTHERS	14	15	19	20	21	24
	TOTAL	115	116	111	101	88	80
SO2+NOx2+ CO2 Tax/ NOx2	POWER PLANTS	1.00	0.99	0.99	0.92	0.84	0.57
	INDUSTRY	1.00	0.99	0.91	0.80	0.81	0.82
	TRANSPORTATION	1.00	1.00	1.00	1.00	0.97	1.01
	OTHERS	1.00	1.00	1.10	1.05	1.05	1.13
	TOTAL	1.00	0.99	0.97	0.89	0.87	0.86

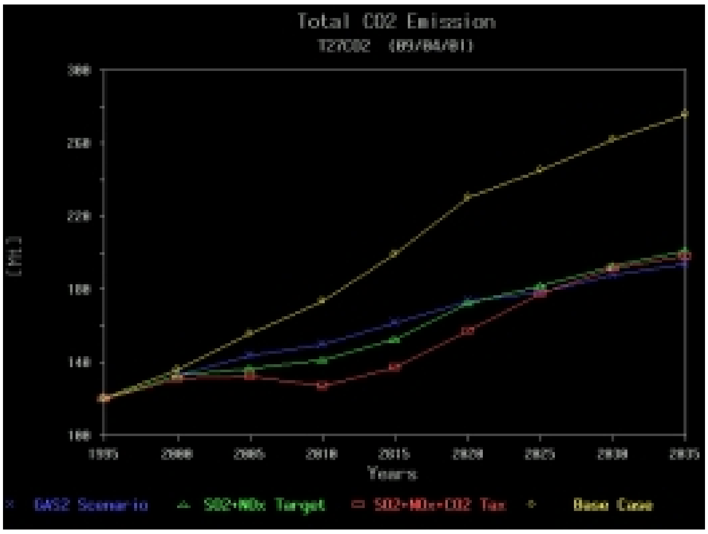

Figure 7.13(a): *CO_2 Emission of BC, GAS2, NOx and SO2+NOx+CO2 Tax Scenario*

图 7.13(a): *BC, GAS2, SO2+NOx 和 SO2+NOx+CO2 排放税情景下上海市 CO_2 排放量*

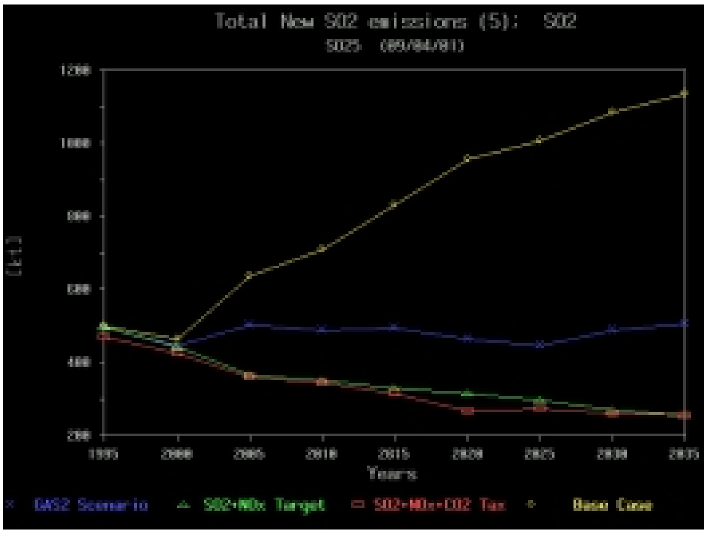

Figure 7.13(b): *SO_2 Emission of BC, GAS2, NOx and SO2+NOx+CO2 Tax Scenario*

图 7.13(b): *BC, GAS2, SO2+NOx 和 SO2+NOx+CO2 排放税情景下上海市 SO_2 排放量*

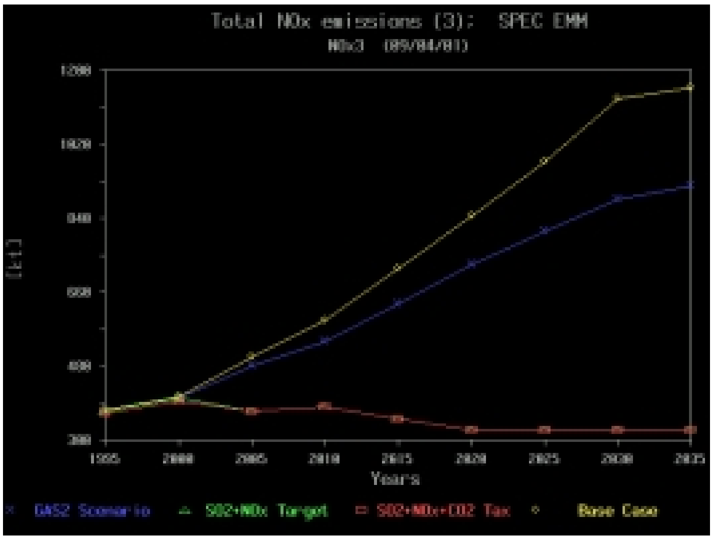

Figure 7.13(c): *NOx Emission of BC, GAS2, NOx and SO2+NOx+CO2 Tax Scenario*

图 7.13(c): *BC, GAS2, SO2+NOx 和 SO2+NOx+CO2 排放税情景下上海市 NOx 排放量*

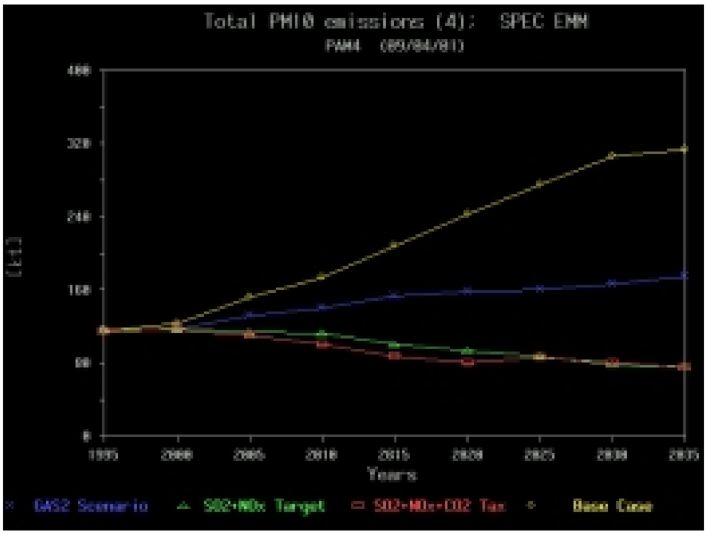

Figure 7.13(d): *PM_{10} Emission of BC, GAS2, NOx and SO2+NOx+CO2 Tax Scenario*

图 7.13(d): *BC, GAS2, SO2+NOx 和 SO2+NOx+CO2 排放税情景下上海市 PM_{10} 排放量*

7.5.9 SO_2+NOx+PM_{10} Emission Target + CO_2 Tax Scenario

Table 7.31-7.32 and Figure 7.14 shows the CO_2 and local air pollutant emissions from energy system when CO_2 tax was added on the base of SO2+NOx+PM10 emission control targets scenario.

From the model results we can see, if CO_2 tax added onward SO2+NOx+PM10 emission control targets scenario, the total CO_2 emission could have a further 5% reduction, and there were no emission reduction on local air pollutants could be achieved by this scenario.

表 7.31: *SO2+NOx+PM10+CO2 税和 SO2+NOx+PM10 情景下上海市 CO_2 排放量的比较 [Mt]*

Table 7.31: *CO_2 Emission of SO2+NOx+PM10+CO2 Tax and PM10 Scenario [Mt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
PM10	POWER PLANTS	36	44	44	45	47	58
	INDUSTRY	66	65	60	57	53	51
	TRANSPORTATION	5	7	8	11	12	14
	OTHERS	14	17	23	29	37	44
	TOTAL	120	133	136	142	148	167
SO2+NOx2+ PM10+CO2 Tax	POWER PLANTS	36	44	43	43	44	57
	INDUSTRY	66	64	59	47	46	45
	TRANSPORTATION	5	7	8	11	14	15
	OTHERS	14	17	23	29	34	42
	TOTAL	120	131	133	129	137	159
SO2+NOx2+ PM10+CO2 Tax/PM10	POWER PLANTS	1.00	0.99	0.98	0.94	0.93	0.99
	INDUSTRY	1.00	0.98	0.98	0.83	0.87	0.89
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.16	1.05
	OTHERS	1.00	1.00	1.00	0.98	0.92	0.95
	TOTAL	1.00	0.99	0.98	0.91	0.92	0.95

表 7.32(a): *SO2+NOx+PM10+CO2 税和 SO2+NOx+PM10 情景下上海市 SO_2 排放量的比较 [kt]*

Table 7.32(a): *SO_2 Emission of SO2+NOx+PM10+CO2 Tax and PM10 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
PM10	POWER PLANTS	281	212	187	187	150	132
	INDUSTRY	151	171	133	123	110	70
	OTHERS	69	58	52	45	40	31
	TOTAL	500	442	372	355	300	232
SO2+NOx2+ PM10+CO2 Tax	POWER PLANTS	281	195	187	187	162	143
	INDUSTRY	151	172	125	117	101	86
	OTHERS	69	58	52	47	43	39
	TOTAL	500	425	364	350	306	267
SO2+NOx2+ PM10+CO2 Tax /PM10	POWER PLANTS	1.00	0.92	1.00	1.00	1.08	1.08
	INDUSTRY	1.00	1.01	0.94	0.95	0.92	1.23
	OTHERS	1.00	1.00	1.00	1.05	1.07	1.26
	TOTAL	1.00	0.96	0.98	0.99	1.02	1.15

表 7.32(b): *SO2+NOx+PM10+CO2 税和 SO2+NOx+PM10 情景下上海市 NOx 排放量的比较 [kt]*

Table 7.32(b): *NOx Emission of SO2+NOx+PM10+CO2 Tax and PM10 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
PM10	POWER PLANTS	155	165	107	94	65	33
	INDUSTRY	98	100	115	122	132	122
	TRANSPORTATION	80	89	40	36	43	25
	OTHERS	39	46	71	88	114	145
	TOTAL	372	399	332	340	353	325
SO2+NOx2+ PM10+CO2 Tax	POWER PLANTS	155	160	124	106	65	33
	INDUSTRY	98	100	107	126	132	134
	TRANSPORTATION	80	89	40	36	42	25
	OTHERS	39	46	73	88	113	133
	TOTAL	372	394	344	356	352	325
SO2+NOx2+ PM10+CO2 Tax /PM10	POWER PLANTS	1.00	0.97	1.16	1.13	1.00	0.99
	INDUSTRY	1.00	1.00	0.93	1.03	1.00	1.10
	TRANSPORTATION	1.00	1.00	1.00	1.00	0.96	1.00
	OTHERS	1.00	1.00	1.03	1.00	1.00	0.91
	TOTAL	1.00	0.99	1.04	1.05	1.00	1.00

表 7.32(c): *SO2+NOx+PM10+CO2 税和 SO2+NOx+PM10 情景下上海市 PM_{10} 排放量的比较* *[kt]*

Table 7.32(c): *PM_{10} Emission of SO2+NOx+PM10+CO2 Tax and PM10 Scenario [kt]*

Case	Sectors	1995	2000	2005	2010	2015	2020
PM10	POWER PLANTS	37	42	28	25	17	8
	INDUSTRY	57	52	50	48	45	44
	TRANSPORTATION	8	6	7	6	5	4
	OTHERS	14	15	17	17	18	19
	TOTAL	115	116	102	96	85	74
SO2+NOx2+ PM10+CO2 Tax	POWER PLANTS	37	42	32	30	19	9
	INDUSTRY	57	52	48	41	41	40
	TRANSPORTATION	8	6	7	6	5	4
	OTHERS	14	15	18	19	20	21
	TOTAL	115	115	106	96	85	74
SO2+NOx2+ PM10+CO2 Tax /PM10	POWER PLANTS	1.00	0.99	1.15	1.19	1.10	1.16
	INDUSTRY	1.00	0.99	0.98	0.87	0.92	0.93
	TRANSPORTATION	1.00	1.00	1.00	1.00	1.00	1.00
	OTHERS	1.00	1.00	1.04	1.10	1.10	1.11
	TOTAL	1.00	0.99	1.04	1.00	1.00	1.00

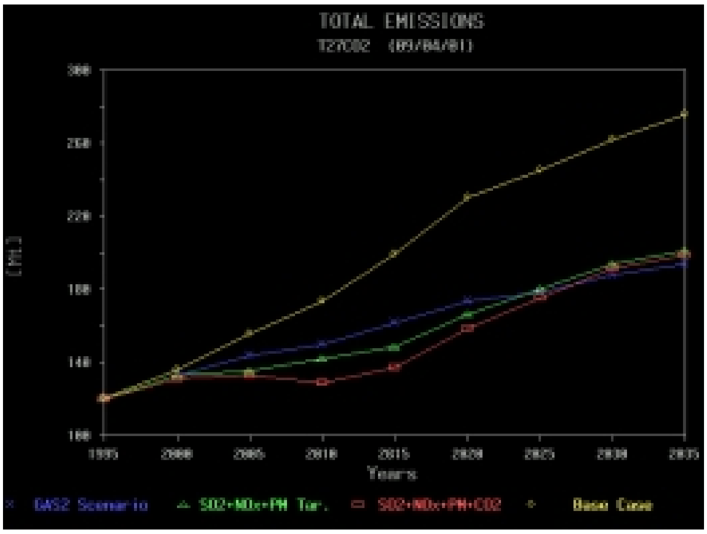

Figure 7.14(a): *CO_2 Emission of BC, GAS2, PM_{10} and SO2+NOx+PM10+CO2 Tax Scenario*

图 7.14(a): *BC, GAS2, SO2+NOx+PM10 和 SO2+NOx+PM10+CO2 排放税情景下 CO_2 排放量*

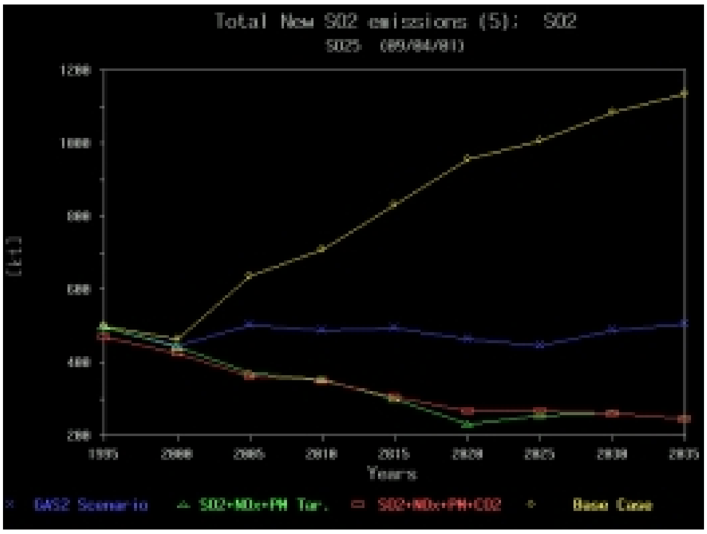

Figure 7.14(b): *SO_2 Emission of BC, GAS2, PM_{10} and SO2+NOx+PM10+CO2 Tax Scenario*

图 7.14(b): *BC, GAS2, SO2+NOx+PM10 和 SO2+NOx+PM10+CO2 排放税情景下 SO_2 排放量*

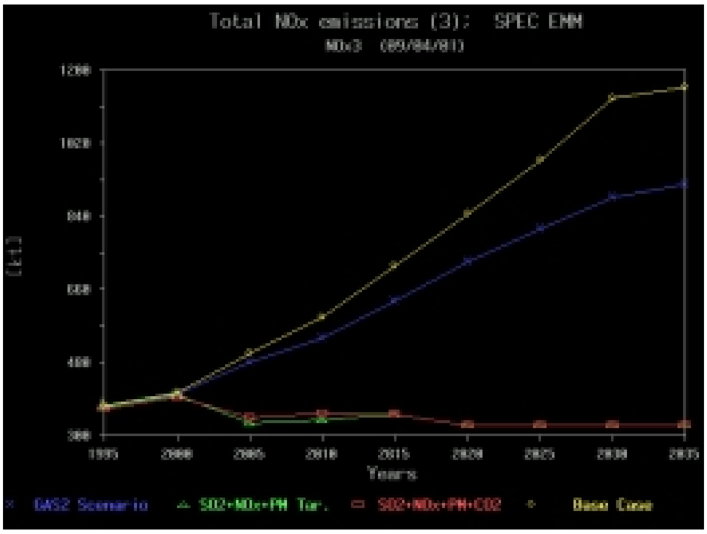

Figure 7.14(c): *NOx Emission of BC, GAS2, PM_{10} and SO2+NOx+PM10+CO2 Tax Scenario*
图 7.14(c): *BC, GAS2, SO2+NOx+PM10 和 SO2+NOx+PM10+CO2 排放税情景下 NOx 排放量*

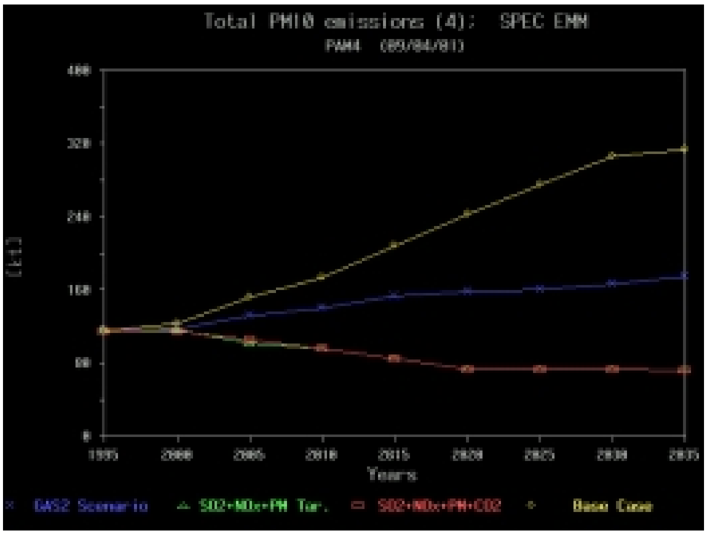

Figure 7.14(d): *PM_{10} Emission of BC, GAS2, PM_{10} and SO2+NOx+PM10+CO2 Tax Scenario*
图 7.14(d): *BC, GAS2, SO2+NOx+PM10 和 SO2+NOx+PM10+CO2 排放税情景下 PM_{10} 排放量*

7.6 Conclusions

In this study, a MARKet ALLocation Model (MARKAL) was used for emission analysis from Shanghai energy system. The scenarios include energy efficiency improvement (EFF), natural gas supply (GAS1), expanding gas use for final sectors (GAS2), total emission control for SO2, NOx and PM10, and as well as CO2 Tax with 200 Yuan per ton CO2 onward 2015.

According to recent studies, energy efficiency improvement, natural gas supply, expanding gas use for final sectors, and SO_2 emission control target will be implemented in the next decades. Natural gas from Western China will reach Shanghai in 2003 or 2004 with a total mount of 3-4 billion cubic meters per year. By then, natural gas will be used for power generation, industry, commercial and residential. Following up the requirement of China Environmental Protection

Agency, the total SO2 emission in Shanghai have to be reduced by from 465 kt in 2000 to 372 kt in 2005, being 20% reduction on base 2000.

Even though, there are no emission control targets for NOx and PM10 reductions, new emission standards, e.g. EURO II and EURO III for new vehicles, is likely to be implemented in 2004 and 2009 (The Ten-fifth Plan for Shanghai Air Quality Protection, SEPB, September 2001). Therefor, the scenario, NOx emission control targets, run with MARKAL model reflect the response of the energy system. For PM10 emission control, lots attentions are now focusing on smoke reduction from fuel burning. It can be presumed that when SO2 and smoke pollution mitigated in five or ten years, much more attention would be played on PM10. The model results show that:

1. The option of energy switch from coal to natural gas, including EFF, GAS1 and GAS2 scenarios, will reduce 25 Mt of CO_2 in 2010 and 56 Mt in 2020, compared to reference case;
2. SO_2 emission control target implement will reduce another 6 Mt of CO_2 in 2010 and 2 Mt in 2020;
3. CO2 tax onward SO_2 emission control scenario will have an extra co-benefit on PM_{10} reduction by 12% in 2020. CO_2 tax onward SO2+NOx emission control targets scenario will produce 10% reduction of CO_2 in 2020;
4. Increasing energy efficiency, implementing energy switch from coal to gas, limiting SO_2 emission, and enforcing new vehicle emission standards will obviously reduce local air pollutant emission from the energy system. The targets achievement will largely depend on the introduction of end-pipe technologies;
5. Due to the fast economic development and its energy demand, the growth of CO_2 emission in Shanghai seems inevitably in the next 20 years. However, the local energy and environmental policy/option could obviously reduce the CO_2 increment ratio.

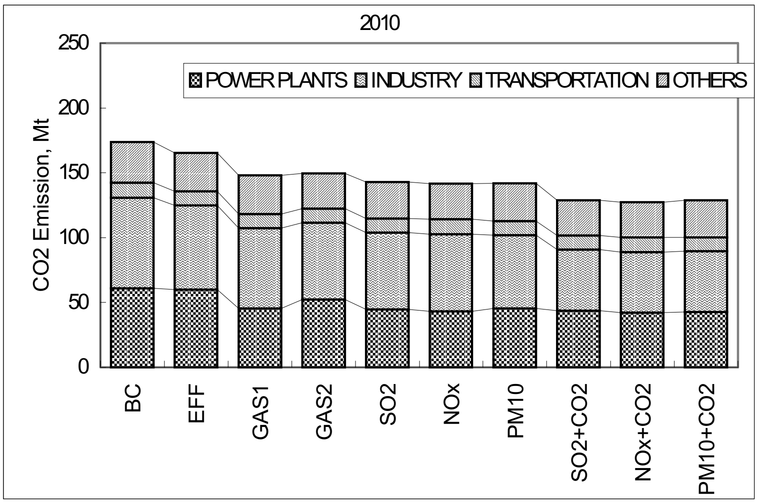

Figure 7.15(a): *CO_2 Emission of different Scenarios, 2010*

图 7.15(a): *各种情景下上海市 CO_2 排放量, 2010 年*

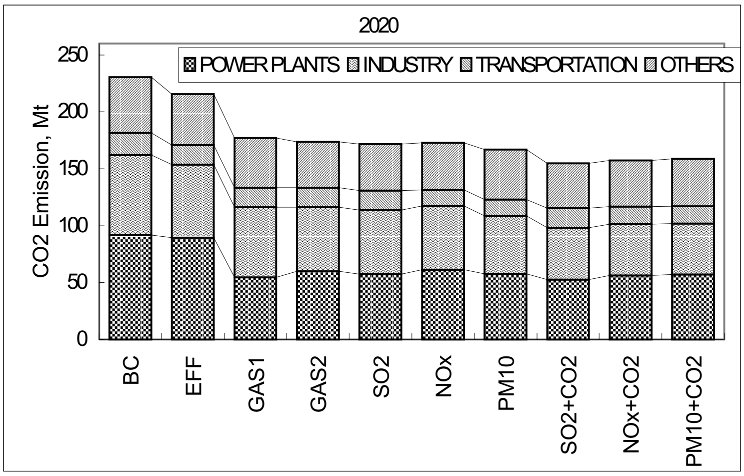

Figure 7.15(b): *CO_2 Emission of different Scenarios, 2020*

图 7.15(b): *各种情景下上海市 CO_2 排放量, 2020 年*

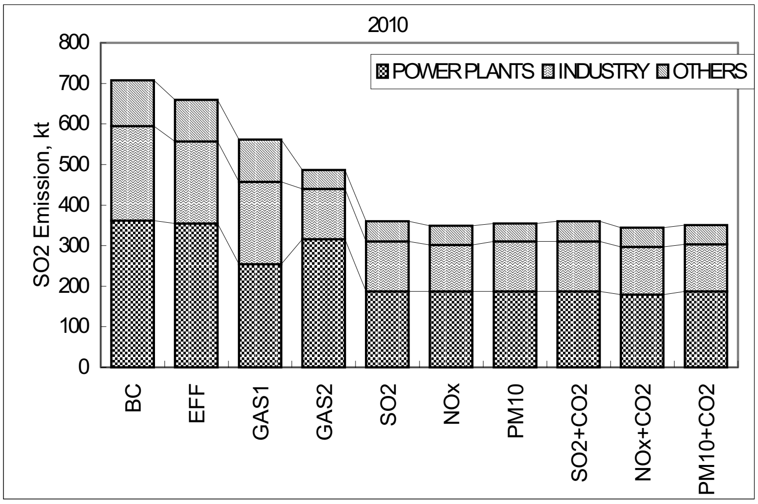

Figure 7.16(a): *SO_2 Emission of different Scenarios, 2010*

图 7.16(a): *各种情景下上海市 SO_2 排放量, 2010 年*

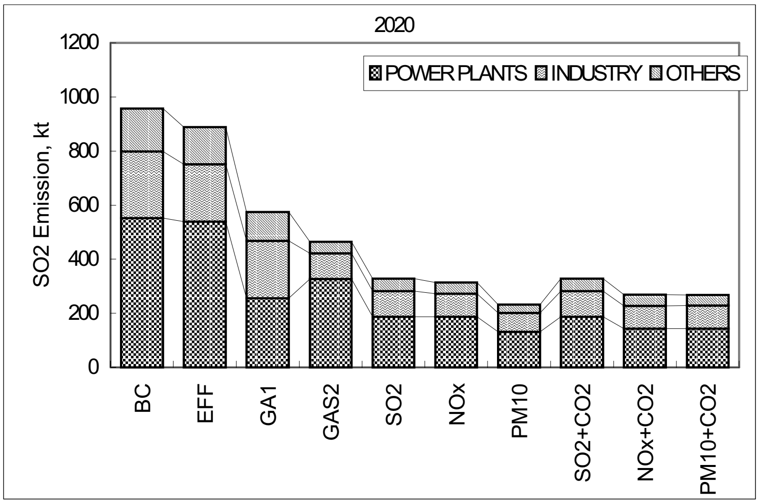

Figure 7.16(b): *SO_2 Emission of different Scenarios, 2020*

图 7.16(b): *各种情景下上海市 SO_2 排放量, 2020 年*

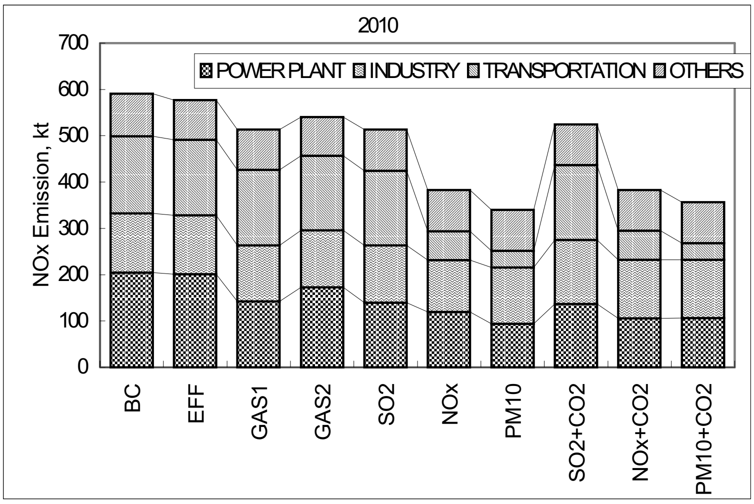

Figure 7.17(a): *NOx Emission of different Scenarios, 2010*

图 7.17(a): *各种情景下上海市 NOx 排放量, 2010 年*

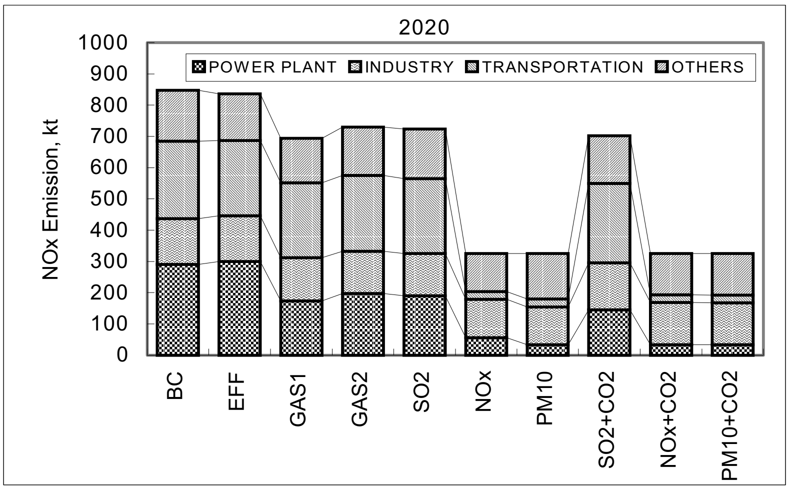

Figure 7.17(b): *NOx Emission of different Scenarios, 2020*

图 7.17(b): *各种情景下上海市 NOx 排放量, 2020 年*

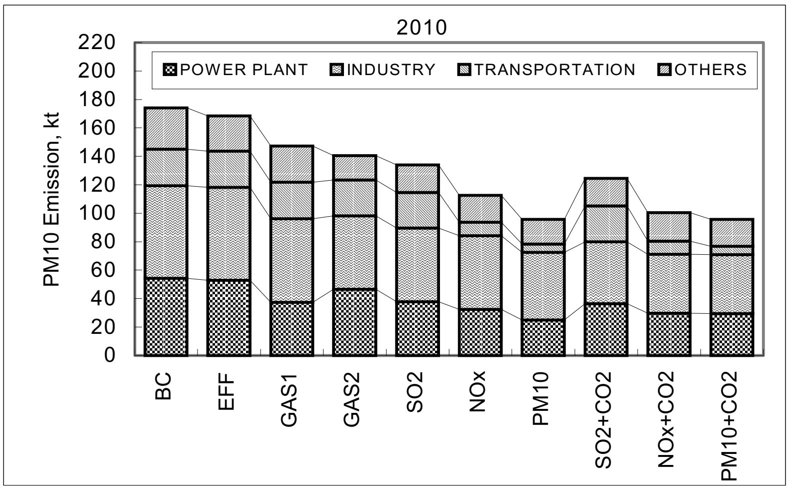

Figure 7.18(a): *PM_{10} Emission of different Scenarios, 2010*

图 7.18(a): *各种情景下上海市PM_{10}排放量, 2010 年*

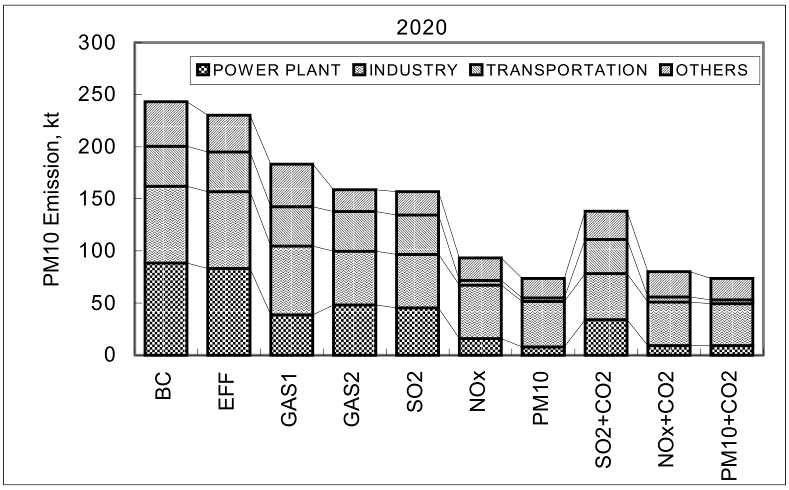

Figure 7.18(b): *PM_{10} Emission of different Scenarios, 2020*

图 7.18(b): *各种情景下上海市PM_{10}排放量, 2020 年*

表 7.33(a): *各种情景下上海市CO_2排放量及减排量* *[Mt]*

Table 7.33(a): *CO_2 Emission and Reduction Ratio under different Scenarios Unit: Mt*

Scenario	Sectors	1995	2005	2010	2020	2005/ 1995	2010/ 1995	2020/ 1995	2020/ BC2020
BC	Power Plants	36	55	61	92	1.53	1.69	2.56	1.00
	Industry	66	68	70	70	1.03	1.06	1.06	1.00
	Transportation	5	8	12	20	1.60	2.40	4.00	1.00
	Others	14	25	31	49	1.79	2.21	3.50	1.00
	Total	**120**	**156**	**174**	**230**	**1.30**	**1.45**	**1.92**	**1.00**
EFF	Power Plants	36	54	60	90	1.50	1.67	2.50	0.98
	Industry	66	64	65	64	0.97	0.98	0.97	0.91
	Transportation	5	8	11	17	1.60	2.20	3.40	0.85
	Others	14	24	30	45	1.71	2.14	3.21	0.92
	Total	**120**	**150**	**165**	**216**	**1.25**	**1.38**	**1.80**	**0.94**
GAS1	Power Plants	36	47	45	55	1.31	1.25	1.53	0.60
	Industry	66	62	62	62	0.94	0.94	0.94	0.89
	Transportation	5	8	11	17	1.60	2.20	3.40	0.85
	Others	14	24	30	44	1.71	2.14	3.14	0.90
	Total	**120**	**141**	**148**	**177**	**1.18**	**1.23**	**1.48**	**0.77**
GAS2	Power Plants	36	53	52	60	1.47	1.44	1.67	0.65
	Industry	66	61	59	56	0.92	0.89	0.85	0.80
	Transportation	5	8	11	17	1.60	2.20	3.40	0.85
	Others	14	22	27	40	1.57	1.93	2.86	0.82
	Total	**120**	**144**	**149**	**174**	**1.20**	**1.24**	**1.45**	**0.76**
SO2 Target	Power Plants	36	45	45	57	1.25	1.25	1.58	0.62
	Industry	66	61	59	56	0.92	0.89	0.85	0.80
	Transportation	5	8	11	17	1.60	2.20	3.40	0.85
	Others	14	23	28	41	1.64	2.00	2.93	0.84
	Total	**120**	**137**	**143**	**172**	**1.14**	**1.19**	**1.43**	**0.75**
SO2+NOx1 Targets	Power Plants	36	46	45	58	1.28	1.25	1.61	0.63
	Industry	66	61	59	56	0.92	0.89	0.85	0.80
	Transportation	5	8	12	14	1.60	2.40	2.80	0.70
	Others	14	23	28	47	1.64	2.00	3.36	0.96
	Total	**120**	**139**	**144**	**175**	**1.16**	**1.20**	**1.46**	**0.76**
SO2+NOx2 Targets	Power Plants	36	44	43	61	1.22	1.19	1.69	0.66
	Industry	66	61	59	56	0.92	0.89	0.85	0.80
	Transportation	5	8	12	14	1.60	2.40	2.80	0.70
	Others	14	23	28	41	1.64	2.00	2.93	0.84
	Total	**120**	**136**	**142**	**173**	**1.13**	**1.18**	**1.44**	**0.75**
SO2+NOx2+ PM10 Targets	Power Plants	36	44	45	58	1.22	1.25	1.61	0.63
	Industry	66	60	57	51	0.91	0.86	0.77	0.73
	Transportation	5	8	11	14	1.60	2.20	2.80	0.70
	Others	14	23	29	44	1.64	2.07	3.14	0.90
	Total	**120**	**136**	**142**	**167**	**1.13**	**1.18**	**1.39**	**0.73**
SO2 Target + CO2 Tax	Power Plants	36	44	44	53	1.22	1.22	1.47	0.58
	Industry	66	59	47	46	0.89	0.71	0.70	0.66
	Transportation	5	8	11	17	1.60	2.20	3.40	0.85
	Others	14	23	27	39	1.64	1.93	2.79	0.80
	Total	**120**	**134**	**129**	**155**	**1.12**	**1.08**	**1.29**	**0.67**
SO2+NOx1 Targets + CO2 Tax	Power Plants	36	44	44	53	1.22	1.22	1.47	0.58
	Industry	66	59	47	46	0.89	0.71	0.70	0.66
	Transportation	5	8	11	15	1.60	2.20	3.00	0.75
	Others	14	23	27	45	1.64	1.93	3.21	0.92
	Total	**120**	**135**	**129**	**158**	**1.13**	**1.08**	**1.32**	**0.69**
SO2+NOx2 Targets + CO2 Tax	Power Plants	36	43	42	56	1.19	1.17	1.56	0.61
	Industry	66	59	46	45	0.89	0.70	0.68	0.64
	Transportation	5	8	12	15	1.60	2.40	3.00	0.75
	Others	14	23	27	41	1.64	1.93	2.93	0.84
	Total	**120**	**133**	**127**	**157**	**1.11**	**1.06**	**1.31**	**0.68**
SO2+NOx2+ PM10 Targets + CO2 Tax	Power Plants	36	43	43	57	1.19	1.19	1.58	0.62
	Industry	66	59	47	45	0.89	0.71	0.68	0.64
	Transportation	5	8	11	15	1.60	2.20	3.00	0.75
	Others	14	23	29	42	1.64	2.07	3.00	0.86
	Total	**120**	**133**	**129**	**159**	**1.11**	**1.08**	**1.33**	**0.69**

表 7.33(b): 各种情景下上海市SO_2排放量及减排量 [kt]

Table 7.33(b): *SO_2 Emission and Reduction Ratio under different Scenarios Unit: kt*

Scenario	Sectors	1995	2005	2010	2020	2005/ 1995	2010/ 1995	2020/ 1995	2020/ BC2020
BC	Power Plants	281	331	362	552	1.18	1.29	1.97	1.00
	Industry	151	216	233	246	1.44	1.55	1.63	1.00
	Others	69	90	113	159	1.30	1.64	2.30	1.00
	Total	**500**	**637**	**707**	**957**	**1.27**	**1.41**	**1.91**	**1.00**
EFF	Power Plants	281	329	355	539	1.17	1.26	1.92	0.98
	Industry	151	191	202	211	1.27	1.35	1.40	0.86
	Others	69	83	103	138	1.21	1.49	2.00	0.87
	Total	**500**	**603**	**660**	**888**	**1.21**	**1.32**	**1.78**	**0.93**
GAS1	Power Plants	281	269	255	256	0.96	0.91	0.91	0.46
	Industry	151	191	203	211	1.27	1.35	1.40	0.86
	Others	69	85	104	106	1.23	1.51	1.54	0.67
	Total	**500**	**545**	**562**	**574**	**1.09**	**1.12**	**1.15**	**0.60**
GAS2	Power Plants	281	320	316	327	1.14	1.13	1.16	0.59
	Industry	151	132	124	95	0.88	0.82	0.63	0.39
	Others	69	51	47	43	0.73	0.68	0.62	0.27
	Total	**500**	**503**	**486**	**464**	**1.00**	**0.97**	**0.93**	**0.48**
SO2 Target	Power Plants	281	187	187	187	0.67	0.67	0.67	0.34
	Industry	151	132	124	95	0.88	0.82	0.63	0.39
	Others	69	53	49	46	0.77	0.71	0.67	0.29
	Total	**500**	**372**	**360**	**328**	**0.74**	**0.72**	**0.66**	**0.34**
SO2+NOx1 Targets	Power Plants	281	187	187	187	0.67	0.67	0.67	0.34
	Industry	151	133	124	95	0.88	0.82	0.63	0.39
	Others	69	52	47	41	0.75	0.68	0.59	0.26
	Total	**500**	**372**	**358**	**323**	**0.74**	**0.72**	**0.65**	**0.34**
SO2+NOx2 Targets	Power Plants	281	187	187	187	0.67	0.67	0.67	0.34
	Industry	151	127	115	86	0.84	0.76	0.57	0.35
	Others	69	52	47	41	0.76	0.69	0.60	0.26
	Total	**500**	**366**	**349**	**314**	**0.73**	**0.70**	**0.63**	**0.33**
SO2+NOx2+ PM10 Targets	Power Plants	281	187	187	132	0.67	0.67	0.47	0.24
	Industry	151	133	123	70	0.89	0.82	0.46	0.28
	Others	69	52	45	31	0.75	0.65	0.45	0.19
	Total	**500**	**372**	**355**	**232**	**0.74**	**0.71**	**0.46**	**0.24**
SO2 Target + CO2 Tax	Power Plants	281	187	187	187	0.67	0.67	0.67	0.34
	Industry	151	132	124	95	0.88	0.82	0.63	0.39
	Others	69	53	49	46	0.77	0.71	0.66	0.29
	Total	**500**	**372**	**360**	**328**	**0.74**	**0.72**	**0.66**	**0.34**
SO2+NOx1 Targets + CO2 Tax	Power Plants	281	187	187	187	0.67	0.67	0.67	0.34
	Industry	151	132	124	95	0.87	0.82	0.63	0.39
	Others	69	52	47	41	0.75	0.68	0.59	0.26
	Total	**500**	**371**	**358**	**323**	**0.74**	**0.72**	**0.65**	**0.34**
SO2+NOx2 Targets + CO2 Tax	Power Plants	281	187	180	143	0.67	0.64	0.51	0.26
	Industry	151	122	117	84	0.81	0.78	0.56	0.34
	Others	69	52	47	41	0.76	0.69	0.60	0.26
	Total	**500**	**361**	**344**	**268**	**0.72**	**0.69**	**0.54**	**0.28**
SO2+NOx2+ PM10 Targets + CO2 Tax	Power Plants	281	187	187	143	0.67	0.67	0.51	0.26
	Industry	151	125	117	86	0.83	0.77	0.57	0.35
	Others	69	52	47	39	0.75	0.68	0.56	0.24
	Total	**500**	**364**	**350**	**267**	**0.73**	**0.70**	**0.53**	**0.28**

表 7.33(c): *各种情景下上海市 NOx 排放量及减排量* *[kt]*

Table 7.33(c): *NOx Emission and Reduction Ratio under different Scenarios Unit: kt*

Scenario	Sectors	1995	2005	2010	2020	2005/ 1995	2010/ 1995	2020/ 1995	2020/ BC2020
BC	Power Plants	155	183	205	290	1.18	1.32	1.87	1.00
	Industry	98	120	128	147	1.23	1.31	1.51	1.00
	Transportation	80	127	166	247	1.57	2.07	3.08	1.00
	Others	39	72	92	163	1.86	2.37	4.19	1.00
	Total	**372**	**502**	**591**	**848**	**1.35**	**1.59**	**2.28**	**1.00**
EFF	Power Plants	155	185	201	300	1.19	1.29	1.93	1.03
	Industry	98	119	127	147	1.21	1.30	1.51	1.00
	Transportation	80	120	163	240	1.50	2.02	2.99	0.97
	Others	39	69	86	149	1.77	2.22	3.84	0.91
	Total	**372**	**492**	**577**	**836**	**1.32**	**1.55**	**2.25**	**0.99**
GAS1	Power Plants	155	148	142	174	0.95	0.92	1.12	0.60
	Industry	98	116	121	139	1.19	1.24	1.42	0.94
	Transportation	80	119	163	239	1.49	2.03	2.98	0.97
	Others	39	69	87	143	1.79	2.23	3.68	0.88
	Total	**372**	**453**	**513**	**694**	**1.22**	**1.38**	**1.87**	**0.82**
GAS2	Power Plants	155	178	173	197	1.15	1.11	1.27	0.68
	Industry	98	118	123	135	1.20	1.26	1.38	0.92
	Transportation	80	121	161	242	1.51	2.00	3.01	0.98
	Others	39	65	84	155	1.68	2.15	3.99	0.95
	Total	**372**	**482**	**540**	**729**	**1.29**	**1.45**	**1.96**	**0.86**
SO2 Target	Power Plants	155	136	140	190	0.88	0.90	1.22	0.65
	Industry	98	120	123	135	1.22	1.26	1.38	0.92
	Transportation	80	121	161	240	1.50	2.01	2.98	0.97
	Others	39	70	89	158	1.81	2.30	4.07	0.97
	Total	**372**	**447**	**514**	**723**	**1.20**	**1.38**	**1.94**	**0.85**
SO2+NOx1 Targets	Power Plants	155	143	144	193	0.92	0.93	1.25	0.67
	Industry	98	120	124	135	1.22	1.27	1.38	0.92
	Transportation	80	61	63	25	0.76	0.79	0.31	0.10
	Others	39	70	90	158	1.79	2.31	4.05	0.97
	Total	**372**	**394**	**420**	**511**	**1.06**	**1.13**	**1.37**	**0.60**
SO2+NOx2 Targets	Power Plants	155	130	119	57	0.83	0.77	0.37	0.20
	Industry	98	109	112	122	1.12	1.14	1.24	0.83
	Transportation	80	61	63	25	0.75	0.78	0.31	0.10
	Others	39	71	89	121	1.82	2.29	3.13	0.75
	Total	**372**	**370**	**383**	**325**	**0.99**	**1.03**	**0.87**	**0.38**
SO2+NOx2+ PM10 Targets	Power Plants	155	107	94	33	0.69	0.60	0.22	0.12
	Industry	98	115	122	122	1.17	1.24	1.24	0.83
	Transportation	80	40	36	25	0.49	0.45	0.31	0.10
	Others	39	71	88	145	1.82	2.27	3.74	0.89
	Total	**372**	**332**	**340**	**325**	**0.89**	**0.91**	**0.87**	**0.38**
SO2 Target + CO2 Tax	Power Plants	155	132	137	145	0.85	0.88	0.93	0.50
	Industry	98	119	138	151	1.21	1.41	1.54	1.02
	Transportation	80	122	161	253	1.52	2.00	3.15	1.03
	Others	39	70	88	152	1.81	2.27	3.93	0.94
	Total	**372**	**443**	**524**	**702**	**1.19**	**1.41**	**1.88**	**0.83**
SO2+NOx1 Targets + CO2 Tax	Power Plants	155	132	136	147	0.85	0.88	0.95	0.51
	Industry	98	119	138	151	1.21	1.41	1.54	1.03
	Transportation	80	70	63	25	0.88	0.79	0.31	0.10
	Others	39	70	88	156	1.79	2.26	4.00	0.96
	Total	**372**	**392**	**425**	**479**	**1.05**	**1.14**	**1.29**	**0.56**
SO2+NOx2 Targets + CO2 Tax	Power Plants	155	129	106	33	0.83	0.68	0.21	0.11
	Industry	98	109	127	135	1.11	1.30	1.38	0.92
	Transportation	80	61	63	25	0.75	0.78	0.31	0.10
	Others	39	71	88	132	1.83	2.26	3.40	0.81
	Total	**372**	**370**	**383**	**325**	**0.99**	**1.03**	**0.87**	**0.38**
SO2+NOx2+ PM10 Targets + CO2 Tax	Power Plants	155	124	106	33	0.80	0.68	0.21	0.11
	Industry	98	107	126	134	1.09	1.29	1.37	0.91
	Transportation	80	40	36	25	0.49	0.45	0.31	0.10
	Others	39	73	88	133	1.87	2.27	3.42	0.82
	Total	**372**	**344**	**356**	**325**	**0.92**	**0.96**	**0.87**	**0.38**

表 7.33(d): *各种情景下上海市 PM_{10} 排放量及减排量* *[kt]*

Table 7.33(d): *PM_{10} Emission and Reduction Ratio under different Scenarios Unit: kt*

Scenario	Sectors	1995	2005	2010	2020	2005/ 1995	2010/ 1995	2020/ 1995	2020/ BC2020
BC	Power Plants	37	50	54	88	1.35	1.47	2.41	1.00
	Industry	57	61	65	74	1.07	1.15	1.30	1.00
	Transportation	8	18	26	39	2.43	3.42	5.15	1.00
	Others	14	23	29	43	1.64	2.04	3.00	1.00
	Total	**115**	**152**	**174**	**243**	**1.32**	**1.51**	**2.11**	**1.00**
EFF	Power Plants	37	49	53	83	1.34	1.44	2.26	0.94
	Industry	57	60	65	74	1.06	1.15	1.30	1.00
	Transportation	8	18	25	38	2.37	3.38	5.07	0.99
	Others	14	20	25	35	1.44	1.76	2.49	0.83
	Total	**115**	**148**	**168**	**230**	**1.28**	**1.46**	**2.00**	**0.95**
GAS1	Power Plants	37	40	37	39	1.09	1.01	1.06	0.44
	Industry	57	57	59	66	1.00	1.04	1.15	0.89
	Transportation	8	18	25	38	2.36	3.38	5.06	0.98
	Others	14	21	26	41	1.51	1.81	2.89	0.96
	Total	**115**	**136**	**147**	**183**	**1.18**	**1.28**	**1.59**	**0.75**
GAS2	Power Plants	37	48	47	48	1.30	1.27	1.31	0.55
	Industry	57	50	51	51	0.88	0.90	0.90	0.70
	Transportation	8	18	25	38	2.37	3.36	5.09	0.99
	Others	14	16	17	21	1.14	1.20	1.48	0.49
	Total	**115**	**132**	**140**	**159**	**1.14**	**1.22**	**1.38**	**0.65**
SO2 Target	Power Plants	37	38	38	45	1.03	1.03	1.23	0.51
	Industry	57	52	52	51	0.91	0.91	0.90	0.70
	Transportation	8	18	25	38	2.37	3.36	5.07	0.98
	Others	14	18	19	22	1.27	1.36	1.58	0.53
	Total	**115**	**126**	**134**	**157**	**1.09**	**1.16**	**1.36**	**0.65**
SO2+NOx1 Targets	Power Plants	37	40	39	46	1.08	1.05	1.24	0.52
	Industry	57	52	52	51	0.91	0.91	0.89	0.69
	Transportation	8	10	9	5	1.25	1.13	0.63	0.13
	Others	14	18	19	22	1.29	1.36	1.57	0.51
	Total	**115**	**119**	**119**	**124**	**1.03**	**1.03**	**1.08**	**0.51**
SO2+NOx2 Targets	Power Plants	37	34	32	16	0.93	0.88	0.44	0.18
	Industry	57	52	52	51	0.92	0.91	0.90	0.69
	Transportation	8	10	9	5	1.32	1.25	0.61	0.12
	Others	14	18	19	22	1.23	1.35	1.52	0.51
	Total	**115**	**114**	**113**	**93**	**0.99**	**0.98**	**0.81**	**0.38**
SO2+NOx2+ PM10 Targets	Power Plants	37	28	25	8	0.76	0.68	0.21	0.09
	Industry	57	50	48	44	0.87	0.84	0.77	0.59
	Transportation	8	7	6	4	0.93	0.78	0.47	0.09
	Others	14	17	17	19	1.23	1.23	1.31	0.44
	Total	**115**	**102**	**96**	**74**	**0.89**	**0.83**	**0.64**	**0.30**
SO2 Target + CO2 Tax	Power Plants	37	36	37	34	0.98	0.99	0.93	0.38
	Industry	57	50	43	44	0.88	0.76	0.77	0.60
	Transportation	8	18	25	33	2.38	3.36	4.43	0.86
	Others	14	18	19	27	1.30	1.36	1.90	0.63
	Total	**115**	**123**	**124**	**138**	**1.06**	**1.08**	**1.20**	**0.57**
SO2+NOx1 Targets + CO2 Tax	Power Plants	37	36	36	34	0.97	0.97	0.92	0.39
	Industry	57	50	44	44	0.88	0.77	0.77	0.59
	Transportation	8	11	8	5	1.38	1.00	0.63	0.13
	Others	14	18	19	23	1.29	1.36	1.64	0.53
	Total	**115**	**115**	**107**	**105**	**1.00**	**0.93**	**0.91**	**0.43**
SO2+NOx2 Targets + CO2 Tax	Power Plants	37	34	30	9	0.92	0.81	0.25	0.10
	Industry	57	48	41	42	0.84	0.73	0.74	0.57
	Transportation	8	10	9	5	1.32	1.25	0.62	0.12
	Others	14	19	20	24	1.35	1.41	1.72	0.57
	Total	**115**	**111**	**101**	**80**	**0.96**	**0.87**	**0.69**	**0.33**
SO2+NOx2+ PM10 Targets + CO2 Tax	Power Plants	37	32	30	9	0.88	0.80	0.25	0.10
	Industry	57	48	41	40	0.85	0.73	0.71	0.55
	Transportation	8	7	6	4	0.93	0.78	0.47	0.09
	Others	14	18	19	21	1.29	1.35	1.45	0.48
	Total	**115**	**106**	**96**	**74**	**0.92**	**0.83**	**0.64**	**0.30**

Table 7.34(a): *Summary of CO2 emission reduction ratio for different scenarios [%]*

Scenario	2000	2005	2010	2015	2020
EFF	-0.02	-0.03	-0.05	-0.06	-0.06
GAS1	-0.01	-0.06	-0.10	-0.15	-0.17
GAS2	0.01	0.02	0.01	0.01	-0.01
SO2	0.00	-0.04	-0.04	-0.03	-0.01
SO2+NOx1	0.00	0.01	0.01	0.01	0.01
SO2+NOx2	0.00	-0.01	-0.01	-0.01	0.00
SO2+NOx2+PM10	0.00	0.00	0.00	-0.02	-0.03
SO2+CO2 Tax	-0.01	-0.02	-0.08	-0.08	-0.07
SO2+NOx1+CO2 Tax	-0.01	-0.03	-0.09	-0.08	-0.07
SO2+NOx2+CO2 Tax	-0.01	-0.02	-0.08	-0.08	-0.07
SO2+NOx2+PM10+CO2 Tax	-0.01	-0.02	-0.08	-0.06	-0.04
Total SO2	**-0.02**	**-0.12**	**-0.18**	**-0.23**	**-0.26**
Total SO2+NOx1	**-0.02**	**-0.11**	**-0.17**	**-0.22**	**-0.24**
Total SO2+NOx2	**-0.02**	**-0.13**	**-0.18**	**-0.23**	**-0.25**
Total SO2+NOx2+PM10	**-0.02**	**-0.13**	**-0.18**	**-0.26**	**-0.28**
Total SO2+CO2 Tax	**-0.03**	**-0.14**	**-0.26**	**-0.30**	**-0.33**
Total SO2+NOx1+CO2 Tax	**-0.03**	**-0.14**	**-0.26**	**-0.30**	**-0.31**
Total SO2+NOx2+CO2 Tax	**-0.03**	**-0.15**	**-0.27**	**-0.31**	**-0.32**
Total SO2+NOx2+PM10+CO2 Tax	**-0.03**	**-0.15**	**-0.26**	**-0.31**	**-0.31**

Table 7.34(b): *Summary of SO2 emission reduction ratio for different scenarios [%]*

Scenario	2000	2005	2010	2015	2020
EFF	-0.04	-0.05	-0.07	-0.07	-0.07
GAS1	0.00	-0.09	-0.14	-0.24	-0.33
GAS2	0.00	-0.07	-0.11	-0.09	-0.12
SO2	0.00	-0.20	-0.18	-0.18	-0.14
SO2+NOx1	0.000	0.000	-0.003	-0.004	-0.005
SO2+NOx2	-0.01	-0.01	-0.01	-0.02	-0.01
SO2+NOx2+PM10	0.00	0.01	0.01	-0.04	-0.08
SO2+CO2 Tax	0.00	0.00	0.00	0.00	0.00
SO2+NOx1+CO2 Tax	-0.002	-0.002	-0.003	-0.004	-0.005
SO2+NOx2+CO2 Tax	-0.04	-0.01	-0.01	-0.02	-0.05
SO2+NOx2+PM10+CO2 Tax	-0.04	-0.01	-0.01	0.01	0.04
Total SO2	**-0.04**	**-0.42**	**-0.49**	**-0.59**	**-0.66**
Total SO2+NOx1	**-0.038**	**-0.416**	**-0.494**	**-0.589**	**-0.662**
Total SO2+NOx2	**-0.045**	**-0.426**	**-0.506**	**-0.604**	**-0.672**
Total SO2+NOx2+PM10	**-0.05**	**-0.42**	**-0.50**	**-0.64**	**-0.76**
Total SO2+CO2 Tax	**-0.04**	**-0.42**	**-0.49**	**-0.59**	**-0.66**
Total SO2+NOx1+CO2 Tax	**-0.04**	**-0.42**	**-0.50**	**-0.59**	**-0.67**
Total SO2+NOx2+CO2 Tax	**-0.08**	**-0.43**	**-0.51**	**-0.62**	**-0.72**
Total SO2+NOx2+PM10+CO2 Tax	**-0.08**	**-0.43**	**-0.50**	**-0.63**	**-0.72**

Table 7.34(c): *Summary of NOx emission reduction ratio for different scenarios [%]*

Scenario	2000	2005	2010	2015	2020
EFF	-0.01	-0.02	-0.02	-0.03	-0.01
GAS1	0.00	-0.08	-0.11	-0.14	-0.17
GAS2	0.00	0.06	0.05	0.06	0.04
SO2	0.00	-0.07	-0.05	-0.04	-0.01
SO2+NOx1	0.00	-0.10	-0.16	-0.21	-0.25
SO2+NOx2	0.00	-0.15	-0.22	-0.35	-0.47
SO2+NOx2+PM10	-0.01	-0.08	-0.07	0.00	0.00
SO2+CO2 Tax	0.00	-0.01	0.02	0.00	-0.03
SO2+NOx1+CO2 Tax	0.00	0.00	0.01	0.00	-0.04
SO2+NOx2+CO2 Tax	-0.01	0.00	0.00	0.00	0.00
SO2+NOx2+PM10+CO2 Tax	-0.01	0.02	0.03	0.00	0.00
Total SO2	**-0.01**	**-0.11**	**-0.13**	**-0.16**	**-0.15**
Total SO2+NOx1	**-0.01**	**-0.22**	**-0.29**	**-0.37**	**-0.40**
Total SO2+NOx2	**-0.01**	**-0.26**	**-0.35**	**-0.51**	**-0.62**
Total SO2+NOx2+PM10	**-0.01**	**-0.34**	**-0.42**	**-0.51**	**-0.62**
Total SO2+CO2 Tax	**-0.01**	**-0.12**	**-0.11**	**-0.16**	**-0.17**
Total SO2+NOx1+CO2 Tax	**-0.01**	**-0.22**	**-0.28**	**-0.37**	**-0.43**
Total SO2+NOx2+CO2 Tax	**-0.02**	**-0.26**	**-0.35**	**-0.51**	**-0.62**
Total SO2+NOx2+PM10+CO2 Tax	**-0.03**	**-0.32**	**-0.40**	**-0.51**	**-0.62**

Table 7.34(d): *Summary of PM_{10} emission reduction ratio for different scenarios [%]*

Scenario	2000	2005	2010	2015	2020
EFF	-0.02	-0.03	-0.03	-0.04	-0.05
GAS1	0.00	-0.07	-0.12	-0.19	-0.19
GAS2	-0.03	-0.03	-0.04	-0.04	-0.10
SO2	0.00	-0.04	-0.04	-0.04	-0.01
SO2+NOx1	0.00	-0.04	-0.08	-0.13	-0.13
SO2+NOx2	0.00	-0.08	-0.12	-0.21	-0.26
SO2+NOx2+PM10	-0.01	-0.08	-0.10	-0.08	-0.08
SO2+CO2 Tax	-0.01	-0.02	-0.05	-0.05	-0.08
SO2+NOx1+CO2 Tax	-0.008	-0.026	-0.069	-0.057	-0.080
SO2+NOx2+CO2 Tax	-0.009	-0.021	-0.070	-0.062	-0.054
SO2+NOx2+PM10+CO2 Tax	-0.01	0.03	0.00	0.00	0.00
Total SO2	**-0.05**	**-0.18**	**-0.23**	**-0.31**	**-0.35**
Total SO2+NOx1	**-0.05**	**-0.22**	**-0.31**	**-0.43**	**-0.49**
Total SO2+NOx2	**-0.05**	**-0.25**	**-0.35**	**-0.51**	**-0.62**
Total SO2+NOx2+PM10	**-0.06**	**-0.33**	**-0.45**	**-0.59**	**-0.70**
Total SO2+CO2 Tax	**-0.06**	**-0.19**	**-0.28**	**-0.36**	**-0.43**
Total SO2+NOx1+CO2 Tax	**-0.06**	**-0.24**	**-0.38**	**-0.49**	**-0.57**
Total SO2+NOx2+CO2 Tax	**-0.06**	**-0.27**	**-0.42**	**-0.58**	**-0.67**
Total SO2+NOx2+PM10+CO2 Tax	**-0.07**	**-0.30**	**-0.45**	**-0.59**	**-0.70**

8. ENERGY OPTION AND AIR POLLUTION EXPOSURE LEVELS

8.1 Introduction

Based on principle of transfer matrix, one type of quick decision air quality model -- Exposure Level model was developed to link emission scenarios of MARKAL model and concentration distribution for health. The fundamental matrix is input by a long range transport and deposition model (ATMOS model, Carmichael et.al., University of Iowa) for sulfur and primary PM_{10}. The model is a Lagrangian parcel model with three vertical layers. The model calculates the ambient concentrations, and the wet and dry deposition of SO_2 and sulfate resulting from area and large point sources. The model also produces transfer matrices for use in exposure level prediction. Two types of matrices are produced: a region-to-grid matrix for the area sources; and a large point source-to-grid matrix for the elevated sources. These matrices are used by Exposure Level model of Shanghai developed in Excel to calculate future SO_2 and primary PM_{10} exposure level under various energy and emissions scenarios prepared by Markal model. Sulfur deposition and primary PM_{10} for the base year 1998 and the transfer matrices of constant emission were incorporated into the Exposure Level model.

8.2 Description of the ATMOS model

The ATMOS model is a three-dimensional, multiple layer Lagrangian model. The ATMOS model was modified to include the calculation of SO_2 and sulfate surface concentrations, and wet and dry deposition amounts. It was also modified to include the capability for modeling both elevated and surface emission sources. The basic features of the ATMOS model are presented in Figure 8.1.

- Modification of BAT Model Developed by Hefter at NOAA
- 3-layer Trajectory Model
- Forward or Backward Trajectories
- Concentrations at Sampling Sites or Grid Locations
- SO2 & Sulfate concentrations, Wet & Dry Deposition
- Source-to Grid Matrix (surface & elevated)

Figure 8.1: *Summary of the ATMOS long range transport model*

8.3 Shanghai Matrix calculated by the ATMOS model

The ATMOS model was initially developed in a one by one degree resolution of the concentrations for regional air quality prediction e.g. RAINS-ASIA model. For Shanghai project, the ATMOS model provides a 4km by 4 km resolution of the concentration and deposition of SO_2 and primary PM_{10}. The pollution modeling domain for Shanghai is 30.655° South to 31.855° North latitude and 121.983° East to 120.814° West longitude. Total area 6341 km^2 of Shanghai is covered by 924 grids of 32 by 28, shown in Figure 8.2.

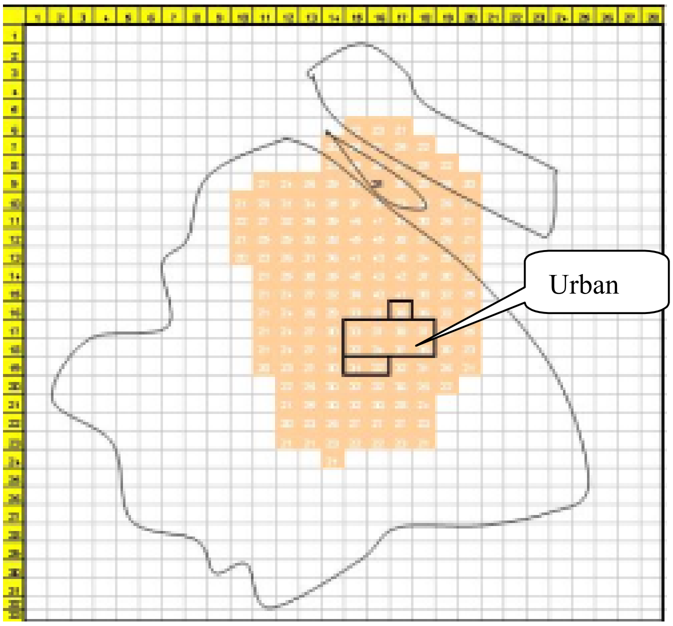

Figure 8.2: *Domain of Shanghai covered by Grids of 4 km by 4 km*

Within the modeling domain SO_2 emission plumes are modeled as puffs released every three hours from the emission source location. Each puff is assigned a mass proportional to the source strength, and is assumed to mix uniformly in the vertical throughout an assigned layer, and to diffuse with a Gaussian distribution in the horizontal. Area emissions are modeled as surface sources (released at the center of the grid) while large point sources are treated as elevated sources. Individual emission puffs are followed throughout their transport and deposition "lifetimes". each puff's transport is followed for up to five days (or until the mass falls below a cut-off value). Puffs which are transported beyond the modeling domain are no longer tracked. As the puffs are being transported, SO_2 is chemically converted to sulfate, and SO_2 and sulfate are deposited to the surface. The deposition of the two pollutants is separated into wet and dry components. Details of the calculations are presented in Reference[1].

8.4 The Exposure Level model

Based on matrix output of the ATMOS model, the Shanghai Exposure Level model was developed in Excel to link the emission prediction of the MARKAL and provide exposure level for health benefit analysis. Emission of SO_2 and PM_{10} are distributed into grids according to location and emission of pollution sources in 2000. For different emission scenarios by energy system, respective spatial exposure level of grids is achieved by transfer matrix quickly. Considering the potential regional cleaner energy replacement and transportation flow rate control in Shanghai, emission from boilers and transportation were further divided into 3 areas of urban, suburban and rural area. In such a way, reasonable distribution of emission could be made to meet future energy policies and emission of motor vehicle in urban could be controlled under saturated limit.

8.5 Exposure Level of different scenarios

(1) Base Case Scenario

Calculated by the Shanghai Exposure Level model, concentration distribution of SO_2 and primary PM_{10} are achieved for base year of 2000 and different scenarios separately. Shown in Figure 8.3 and Figure 8.4, 320 km^2 exceeded the grade II criteria of SO_2 (national standard GB3095-1996: 0.06 mg/m^3) and no area over grade I of PM_{10} (national standard GB3095-1996: 0.04 mg/m^3). Without further air pollution control, more area will exceed SO_2 standard continuously with annual increase of emission. Shown in Table 8.1, total 1184 km^2 exceeded grade II of SO_2 in 2005, which increased to 1600 km^2 in 2010 and 2448 km^2 in 2020 (Figure8.5~8.7). Shown in Table 8.2, 608 km^2 exceeded grade I of PM_{10} in 2005, which increased to 928 km^2 in 2010 and 2080 km^2 in 2020 (Figure8.8~8.10).

Table 8.1: *Exposure level of SO_2 under Base Case scenario (Unit:km^2)*

SO_2(mg/m^3)	2000	2005	2010	2020
0.135~0.15				64
0.12~0.135				160
0.1~0.12			112	464
0.08~0.1		336	480	704
0.06~0.08	320	848	1008	1056
0.05~0.06	560	656	624	800
0.04~0.05	704	800	944	944
0.025~0.04	1952	2048	2160	2384
0.015~0.025	2384	2816	2832	3136
0~0.015	8864	7280	6624	5072
average SO_2(mg/m^3) in urban	0.058	0.077	0.087	0.110

Table 8.2: *Exposure level of PM_{10} under Base Case scenario (Unit:km^2)*

PM_{10}(mg/m^3)	2000	2005	2010	2020
0.07~0.08				240
0.06~0.07				480
0.05~0.06			288	528
0.04~0.05		608	640	832
0.035~0.04	320	336	496	592
0.030~0.035	464	496	544	848
0.02~0.03	1504	1840	2160	2720
0.01~0.02	4192	4752	4928	4944
0.005~0.01	4768	4496	4176	3088
0~0.005	3536	2256	1552	512
average PM_{10} (mg/m^3) in urban	0.035	0.044	0.051	0.069

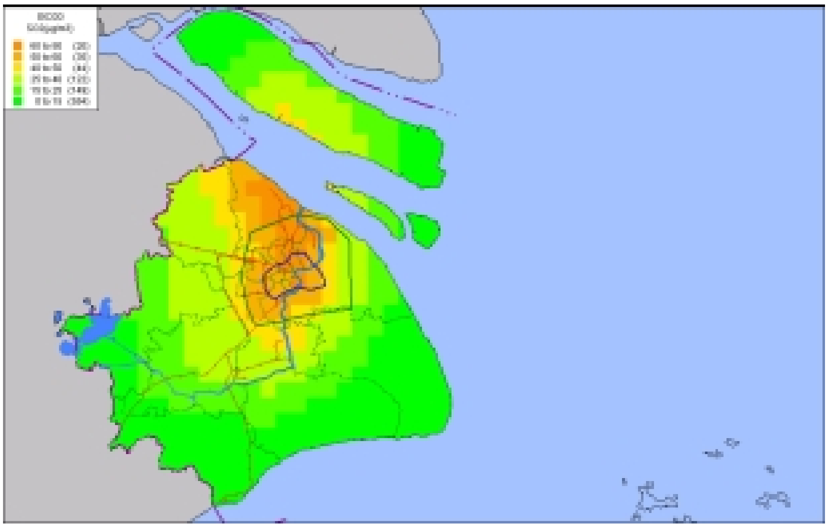

Figure 8.3: *SO_2 exposure level in base year of 2000*

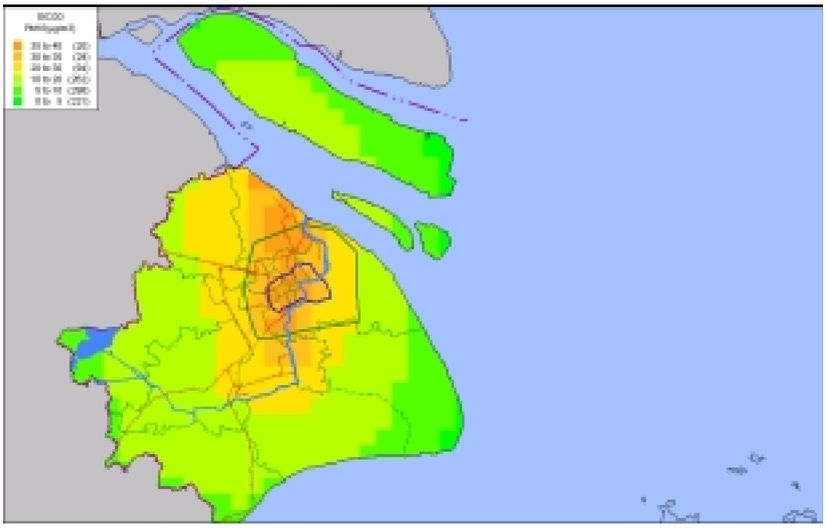

Figure 8.4: *PM_{10} exposure level in base year of 2000*

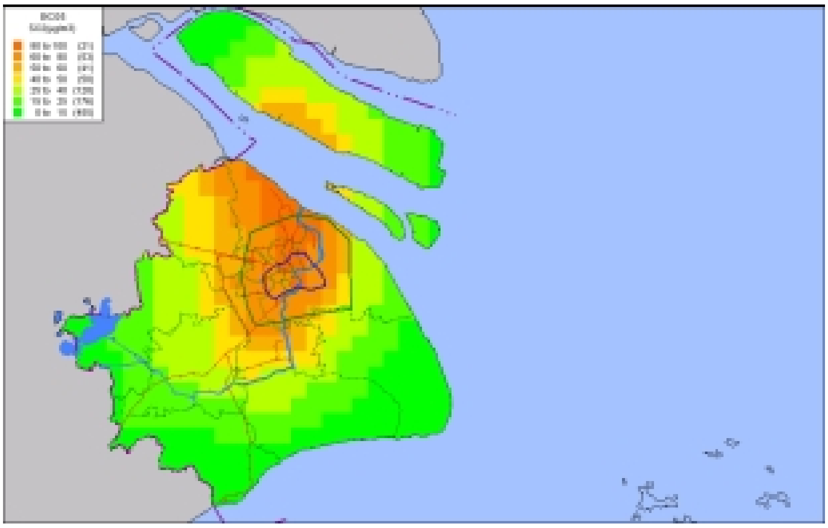

Figure 8.5: *SO_2 exposure level in base case of 2005*

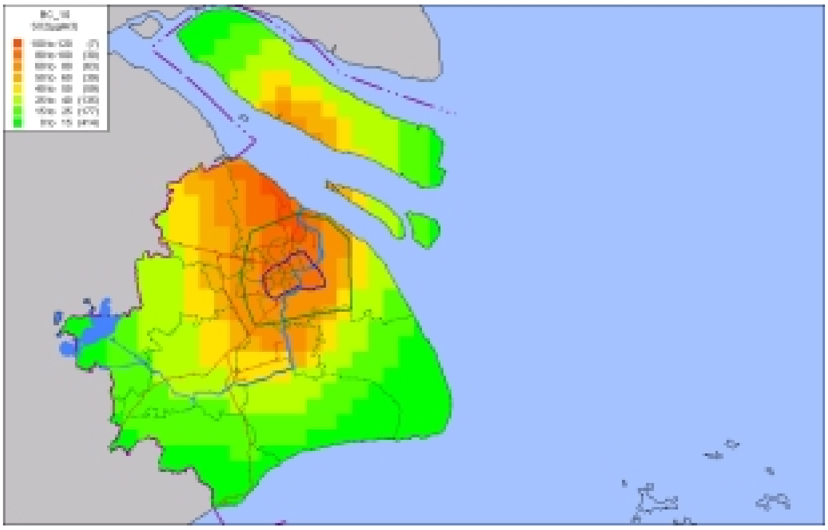

Figure 8.6: *SO_2 exposure level in base case of 2010*

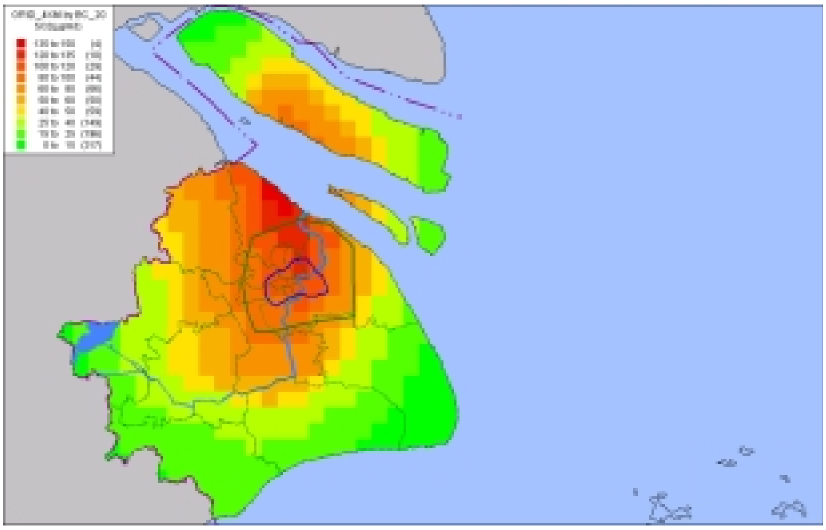

Figure 8.7: *SO_2 exposure level in base case of 2020*

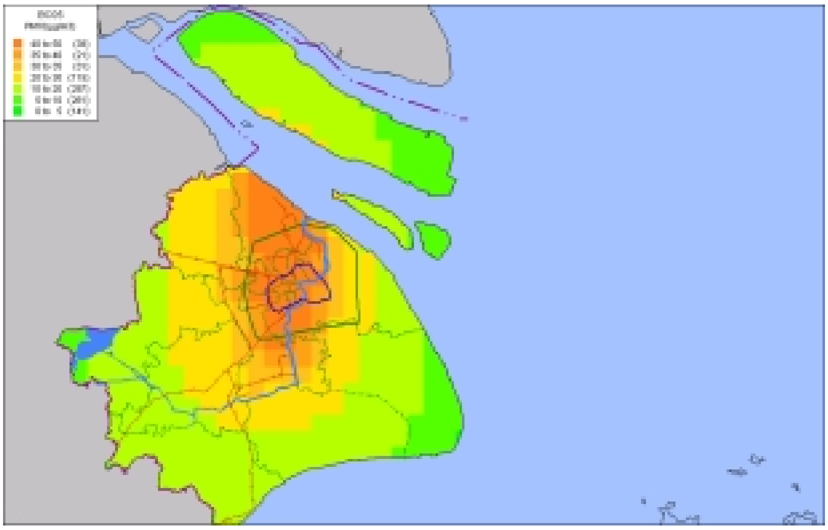

Figure 8.8: *PM_{10} exposure level in base case of 2005*

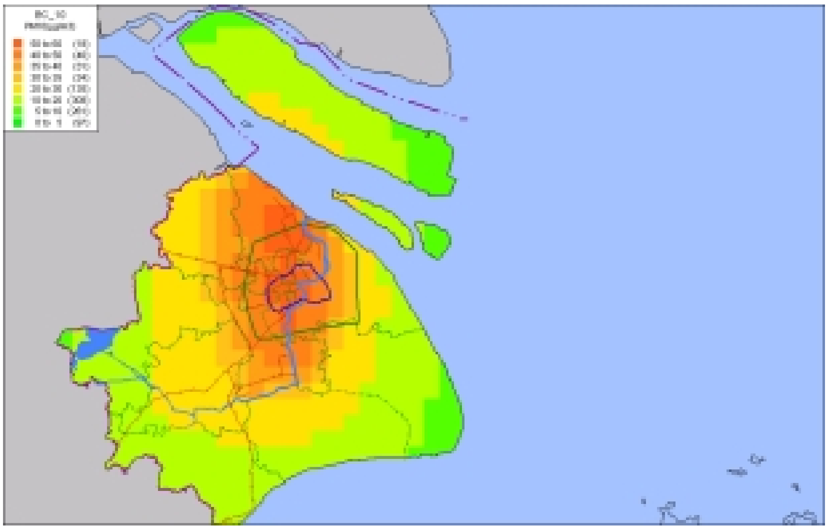

Figure 8.9: *PM_{10} exposure level in base case of 2010*

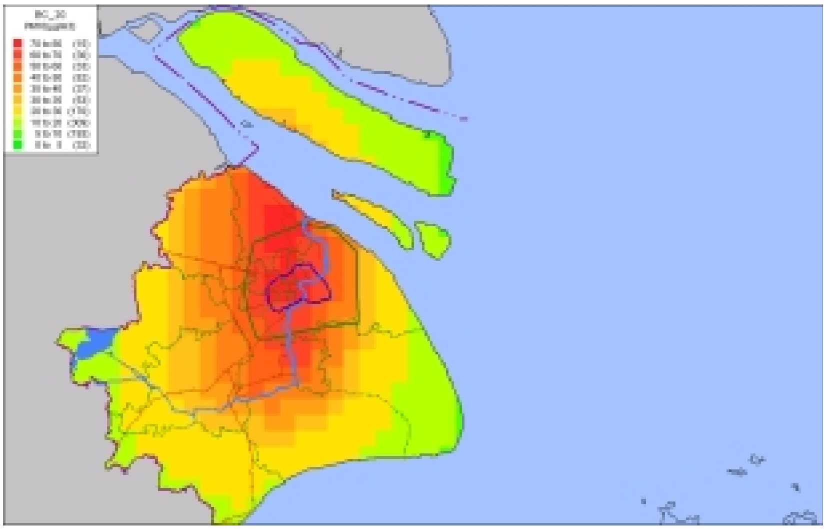

Figure 8.10: *PM_{10} exposure level in base case of 2020*

(2) Energy Efficiency Improvement Scenario

Shown in Table 8.3, comparing with base case, area exceeding standard of SO_2 decreased from 1184 km^2 to 960 km^2 in 2005, which decreased from 1600 km^2 to 1264 km^2 in 2010 and from 2448 km^2 to 2048 km^2 in 2020 (Figure 8.11~8.13). Shown in Table 8.4, area exceeding standard of PM_{10} decreased from 608 km^2 to 176 km^2 of PM_{10} in 2005, which decreased from 928 km^2 to 400 km^2 in 2010 and from 2080 km^2 to 1136 km^2 in 2020 (Figure 8.14~8.16).

Table 8.3: *Exposure level of SO_2 under EFF scenario (Unit:km^2)*

SO_2(mg/m^3)	2000	2005	2010	2020
0.135~0.15				
0.12~0.135				96
0.1~0.12				336
0.08~0.1		176	400	704
0.06~0.08	320	784	864	912
0.05~0.06	560	608	608	720
0.04~0.05	704	816	848	992
0.025~0.04	1952	2000	2112	2304
0.015~0.025	2384	2608	2720	3120
0~0.015	8864	7792	7232	5600
average SO_2(mg/m^3) in urban	0.058	0.071	0.079	0.099

Table 8.4: *Exposure level of PM_{10} under EFF scenario (Unit:km^2)*

PM_{10}(mg/m^3)	2000	2005	2010	2020
0.07~0.08				
0.06~0.07				96
0.05~0.06				336
0.04~0.05		176	400	704
0.035~0.04	320	784	864	912
0.030~0.035	464	608	608	720
0.02~0.03	1504	816	848	992
0.01~0.02	4192	2000	2112	2304
0.005~0.01	4768	2608	2720	3120
0~0.005	3536	7792	7232	5600
average PM_{10} (mg/m^3) in urban	0.035	0.041	0.048	0.064

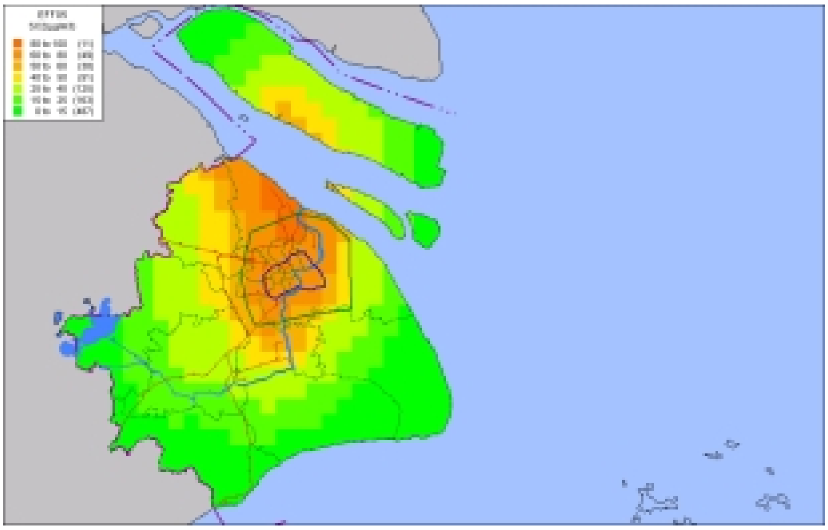

Figure 8.11: *SO_2 exposure level under EFF scenario of 2005*

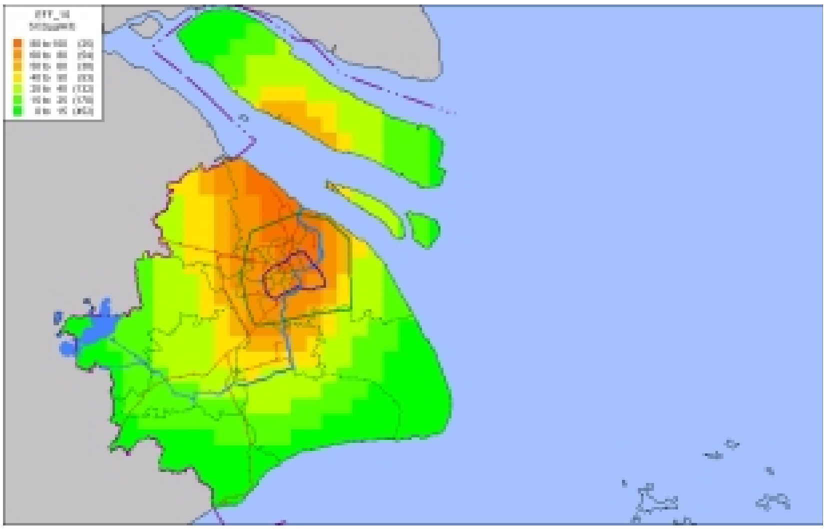

Figure 8.12: *SO_2 exposure level under EFF scenario of 2010*

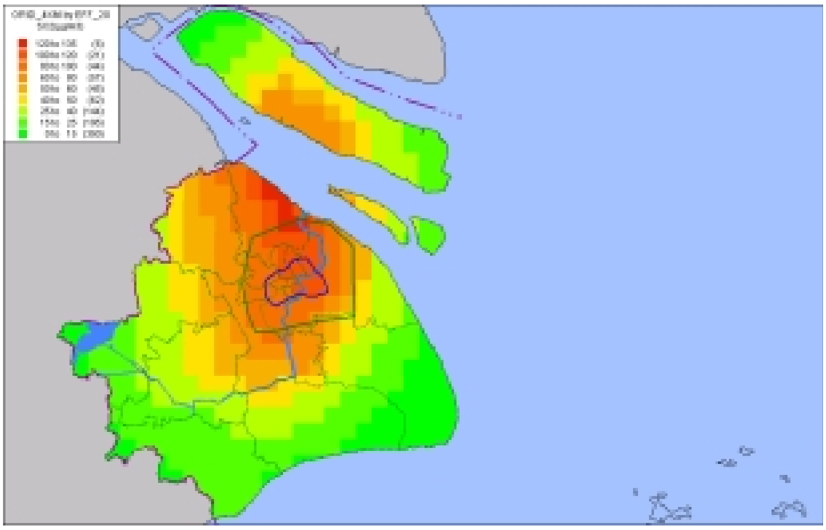

Figure 8.13: *SO_2 exposure level under EFF scenario of 2020*

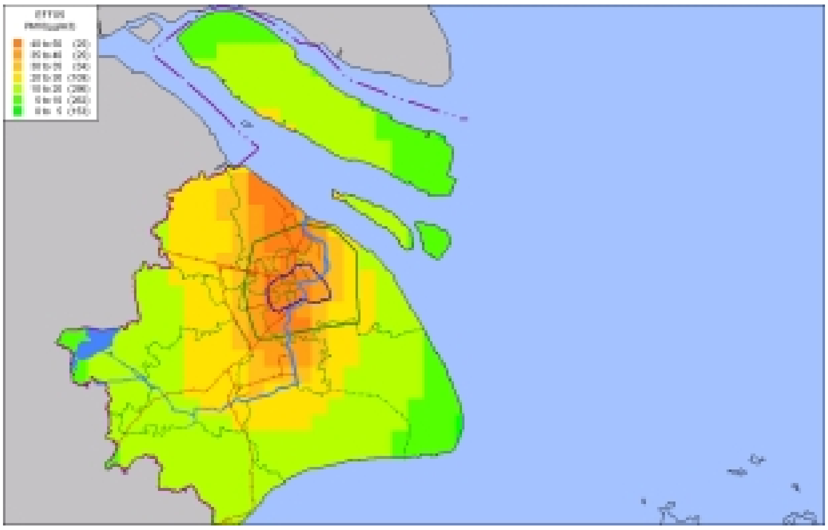

Figure 8.14: *PM_{10} exposure level under EFF scenario of 2005*

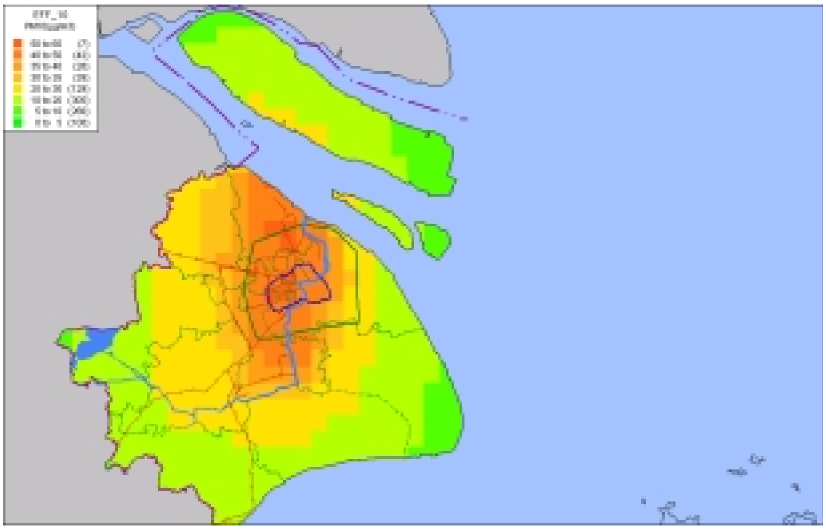

Figure 8.15: *PM_{10} exposure level under EFF scenario of 2010*

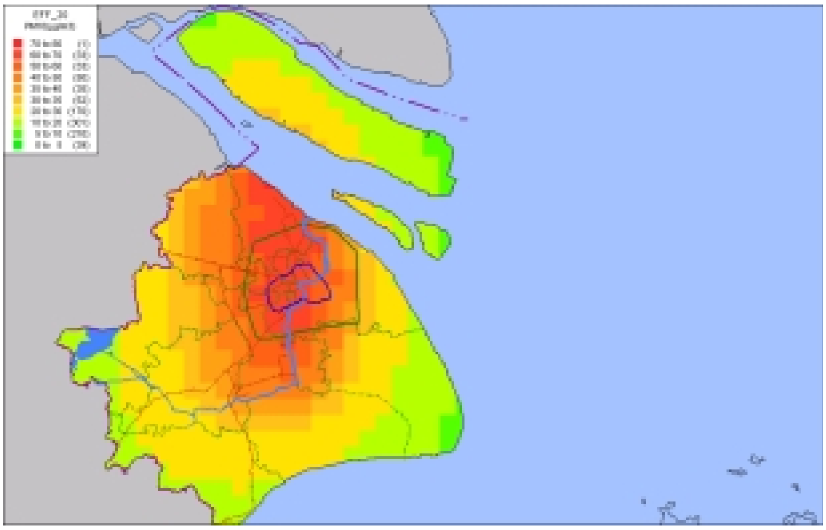

Figure 8.16: *PM_{10} exposure level under EFF scenario of 2020*

(3) Expanding Gas Use Scenario

Shown in Table 8.5, comparing with EFF scenario, area exceeding standard of SO_2 decreased from 960 km^2 to 176 km^2 in 2005, which decreased from 1264 km^2 to 128 km^2 in 2010 and from 2048 km^2 to 48 km^2 in 2020 (Figure8.17~8.19). Shown in Table 8.6, area exceeding standard of PM_{10} decreased from 176 km^2 to 16 of PM_{10} in 2005, which decreased from 400 km^2 to 176 km^2 in 2010 and from 1136 km^2 to 688 km^2 in 2020 (Figure8.20~8.22).

Table 8.5: *Exposure level of SO_2 under GAS2 scenario (Unit:km^2)*

SO_2(mg/m^3)	2000	2005	2010	2020
0.135~0.15				
0.12~0.135				
0.1~0.12				
0.08~0.1				
0.06~0.08	320	176	128	48
0.05~0.06	560	384	384	256
0.04~0.05	704	832	752	624
0.025~0.04	1952	1888	1824	1664
0.015~0.025	2384	2448	2400	3408
0~0.015	8864	9056	9296	8784
average SO_2(mg/m^3) under urban	0.058	0.051	0.049	0.044

Table 8.6: *Exposure level of PM_{10} under GAS2 scenario (Unit:km^2)*

PM_{10}(mg/m^3)	2000	2005	2010	2020
0.07~0.08				
0.06~0.07				
0.05~0.06				
0.04~0.05		16	176	688
0.035~0.04	320	384	496	368
0.030~0.035	464	448	448	512
0.02~0.03	1504	1584	1712	1968
0.01~0.02	4192	4176	4608	4864
0.005~0.01	4768	4720	4592	4464
0~0.005	3536	3136	2752	1920
average PM_{10} (mg/m^3) in urban	0.035	0.036	0.039	0.045

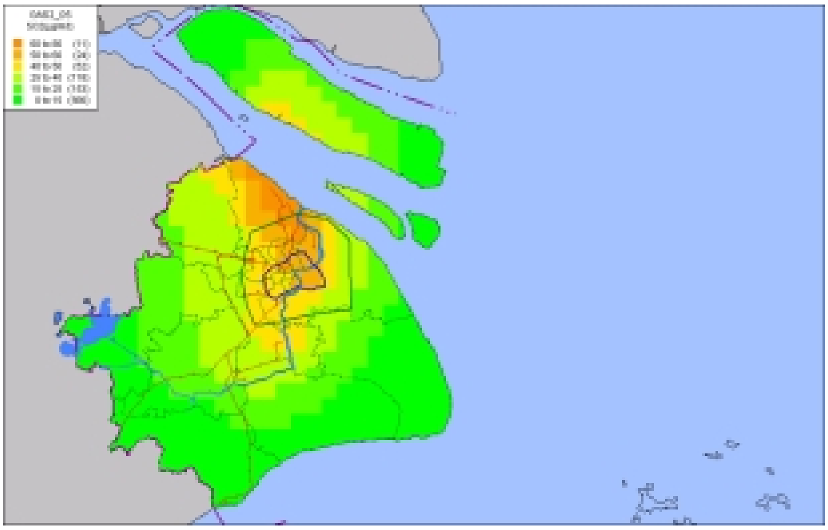

Figure 8.17: *SO_2 exposure level under GAS2 scenario of 2005*

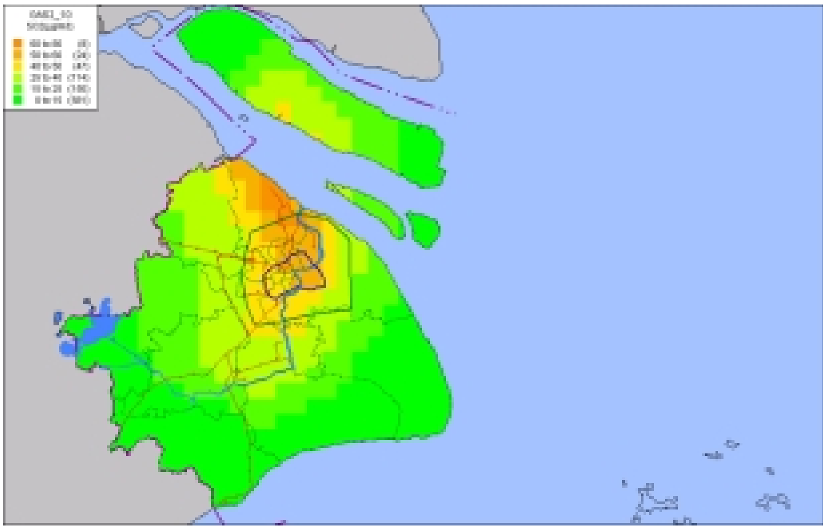

Figure 8.18: *SO_2 exposure level under GAS2 scenario of 2010*

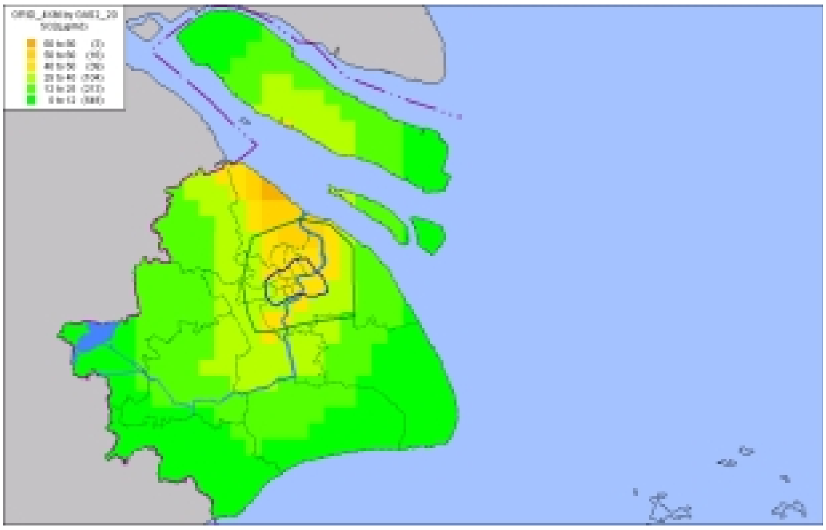

Figure 8.19: *SO_2 exposure level under GAS2 scenario of 2020*

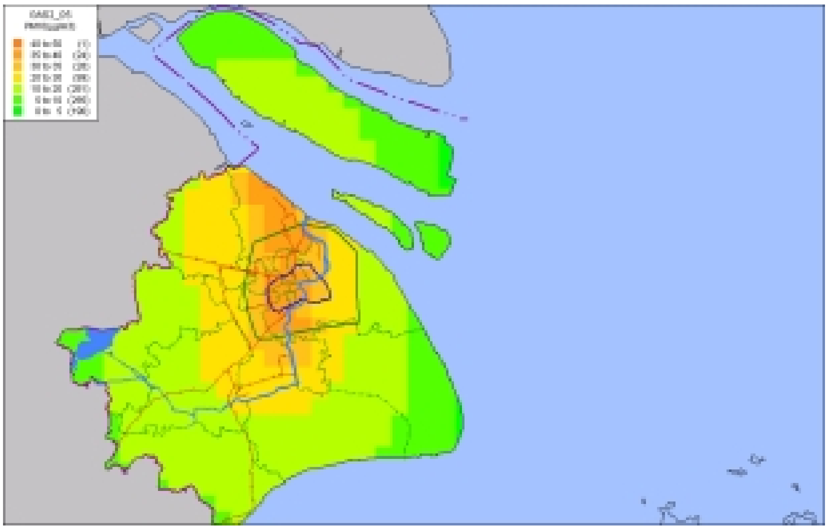

Figure 8.20: *PM_{10} exposure level under GAS2 scenario of 2005*

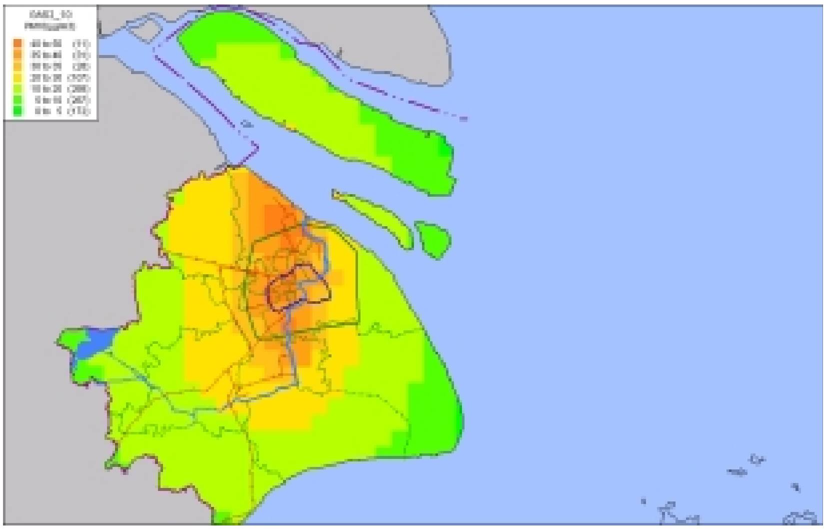

Figure 8.21: *PM_{10} exposure level under GAS2 scenario of 2010*

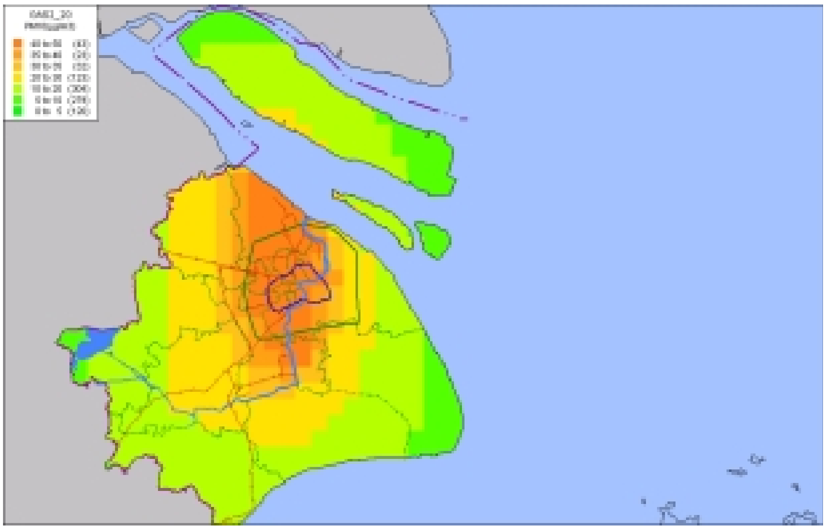

Figure 8.22: *PM_{10} exposure level under GAS2 scenario of 2020*

(4) SO_2 Emission Target Scenario

Shown in Table 8.7, comparing with GAS2 scenario, no area exceeded the standard of SO_2 since 2005. Comparing with the exposure level in 2000, area below than 0.25 mg/m^3 increased from 11248 km^2 to 12448 km^2 in 2005, 12672 km^2 in 2010 and 12976 km^2 in 2020 (Figure8.23~8.25). Shown in Table 8.8, comparing with GAS2 scenario, area exceeding standard of PM_{10} decreased from 16 km^2 to 0 km^2 in 2005, which decreased from 176 km^2 to 64 km^2 in 2010 and from 688 km^2 to 672 km^2 in 2020 (Figure8.26~8.28).

Table 8.7: *Exposure level of SO_2 under SO_2 Target scenario (Unit:km^2)*

SO_2(mg/m^3)	2000	2005	2010	2020
0.135~0.15				
0.12~0.135				
0.1~0.12				
0.08~0.1				
0.06~0.08	320			
0.05~0.06	560	96	48	
0.04~0.05	704	496	432	304
0.025~0.04	1952	1744	1632	1504
0.015~0.025	2384	2288	2320	2064
0~0.015	8864	10160	10352	10912
average SO_2(mg/m^3) in urban	0.058	0.042	0.039	0.036

Table 8.8: *Exposure level of PM_{10} under SO_2 Target scenario (Unit:km^2)*

PM_{10}(mg/m^3)	2000	2005	2010	2020
0.07~0.08				
0.06~0.07				
0.05~0.06				
0.04~0.05			64	672
0.035~0.04	320	304	48	336
0.030~0.035	464	464	464	512
0.02~0.03	1504	1616	1680	1984
0.01~0.02	4192	4368	4608	4896
0.005~0.01	4768	4720	4560	4448
0~0.005	3536	3312	2928	1936
average PM_{10} (mg/m^3) in urban	0.035	0.035	0.038	0.045

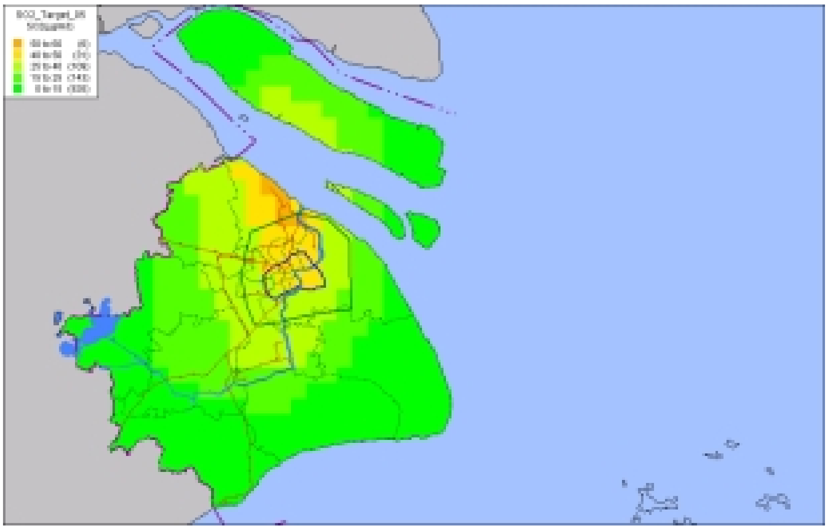

Figure 8.23: *SO_2 exposure level under SO_2 Target scenario of 2005*

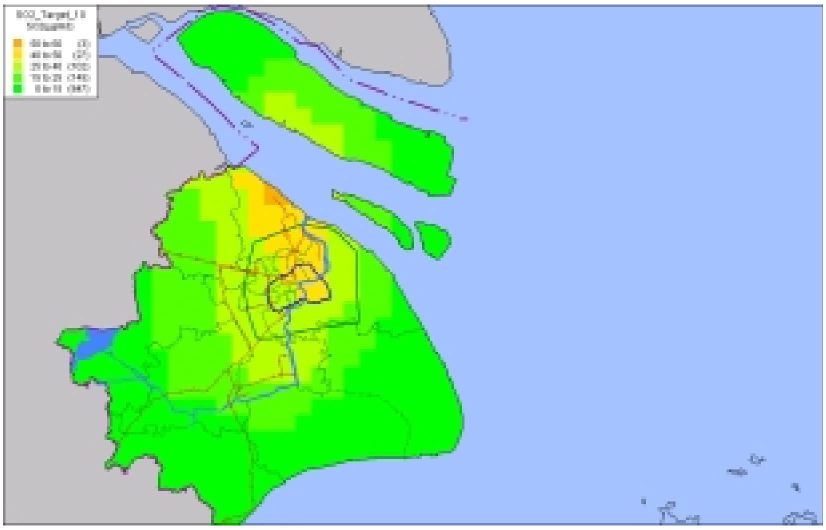

Figure 8.24: *SO_2 exposure level under SO_2 Target scenario of 2010*

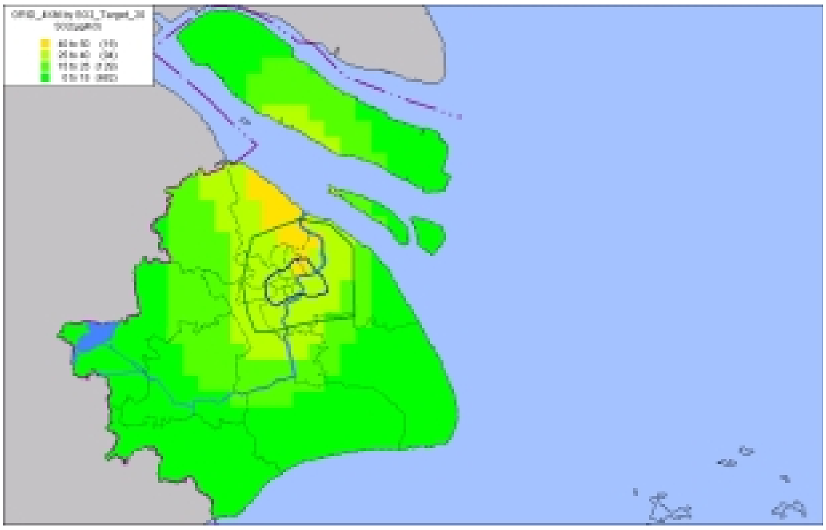

Figure 8.25: *SO_2 exposure level under SO_2 Target scenario of 2020*

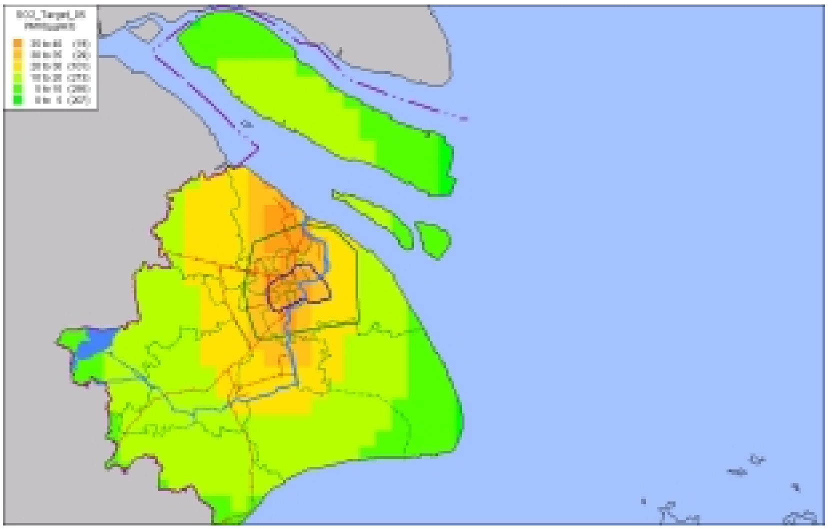

Figure 8.26: *PM_{10} exposure level under SO_2 Target scenario of 2005*

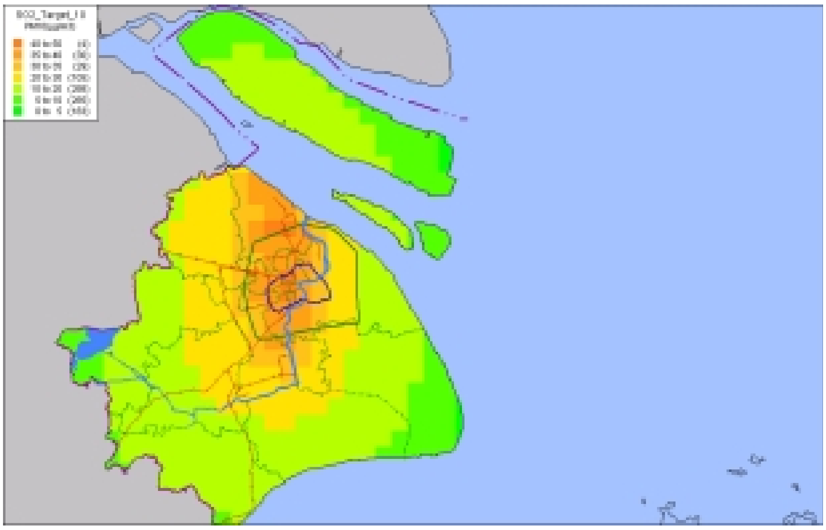

Figure 8.27: *PM_{10} exposure level under SO_2 Target scenario of 2010*

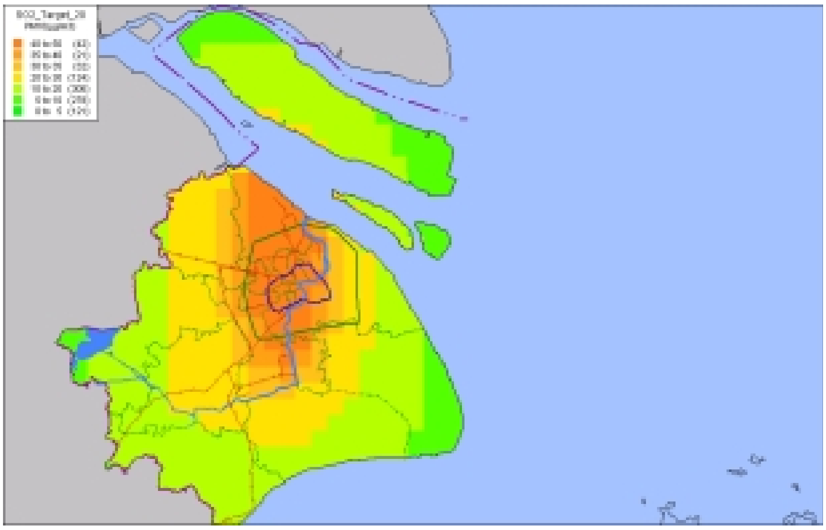

Figure 8.28: *PM_{10} exposure level under SO_2 Target scenario of 2020*

(5) SO2+NOx1 Emission Target Scenario

Shown in Table 8.9, comparing with SO_2 Target scenario, no obvious change happened resulting from NOx emission control. Comparing with the exposure level in 2000, area below than 0.25 mg/m^3 increased from 11248 km^2 to 12320 km^2 in 2005, 12608 km^2 in 2010 and 13136 km^2 in 2020 (Figure 8.29~8.31). Shown in Table 8.10, comparing with SO_2 Target scenario, no more area exceeded the standard of PM_{10} since 2005. Comparing with the exposure level in 2000, area exceeding 0.035mg/m^3 decreased from 320 km^2 to 80 km^2 in 2005, 64 km^2 in 2010 and 176 km^2 in 2020 (Figure 8.32~8.34).

Table 8.9: *Exposure level of SO_2 under SO_2+NOx1 Target scenario (Unit:km^2)*

SO_2(mg/m^3)	2000	2005	2010	2020
0.135~0.15				
0.12~0.135				
0.1~0.12				
0.08~0.1				
0.06~0.08	320			
0.05~0.06	560	96		
0.04~0.05	704	512	464	160
0.025~0.04	1952	1856	1712	1488
0.015~0.025	2384	2272	2352	2096
0~0.015	8864	10048	10256	11040
average SO_2(mg/m^3) in urban	0.058	0.042	0.039	0.035

Table 8.10: *Exposure level of PM_{10} under SO_2+NOx1 Target scenario (Unit:km^2)*

PM_{10}(mg/m^3)	2000	2005	2010	2020
0.07~0.08				
0.06~0.07				
0.05~0.06				
0.04~0.05				
0.035~0.04	320	80	64	176
0.030~0.035	464	544	560	496
0.02~0.03	1504	1424	1424	1520
0.01~0.02	4192	4272	4272	4336
0.005~0.01	4768	4848	4864	4800
0~0.005	3536	3616	3600	3456
average PM_{10} (mg/m^3) in urban	0.035	0.032	0.032	0.033

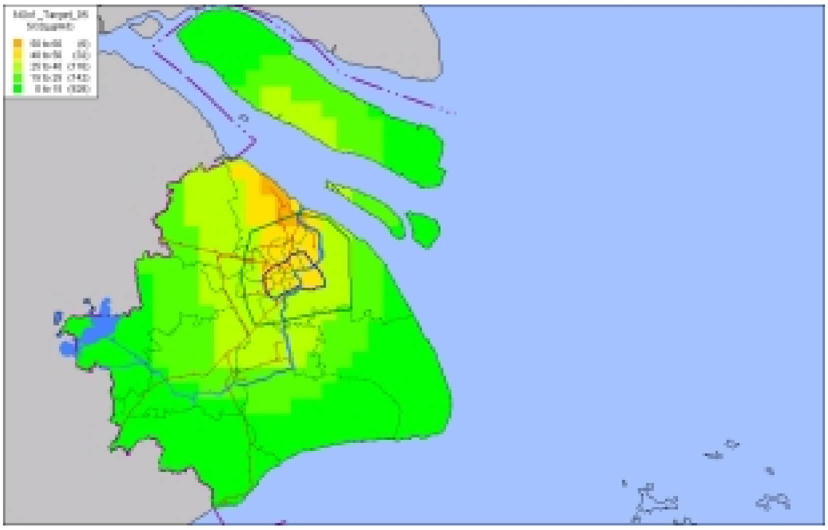

Figure 8.29: *SO_2 exposure level under SO_2+NOx1 Target scenario of 2005*

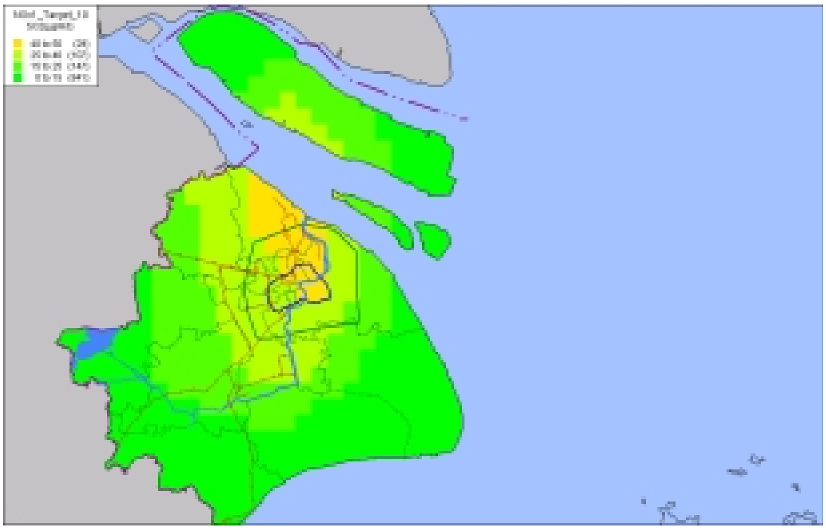

Figure 8.30: *SO_2 exposure level under SO_2+NOx1 Target scenario of 2010*

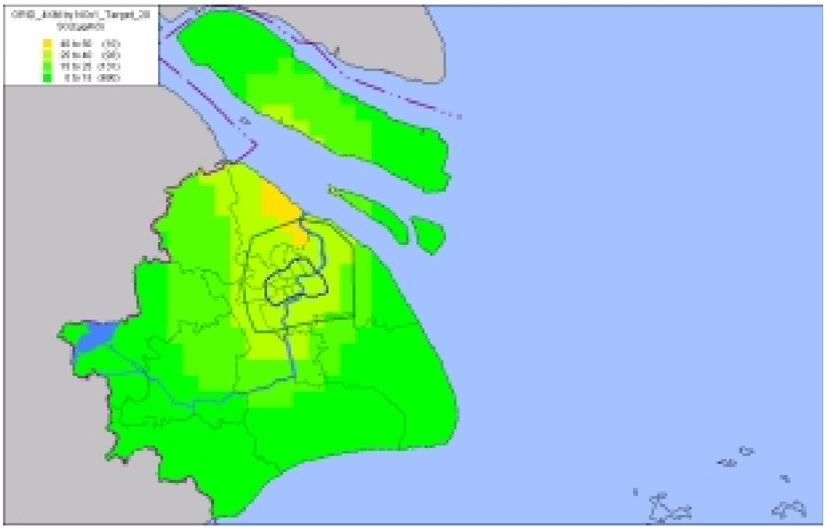

Figure 8.31: *SO_2 exposure level under SO_2+NOx1 Target scenario of 2020*

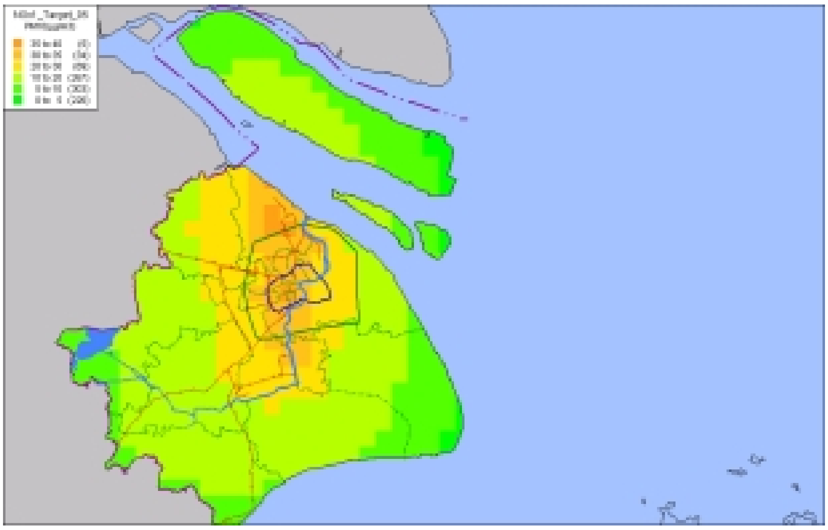

Figure 8.32: *PM_{10} exposure level under SO_2+NOx1 Target scenario of 2005*

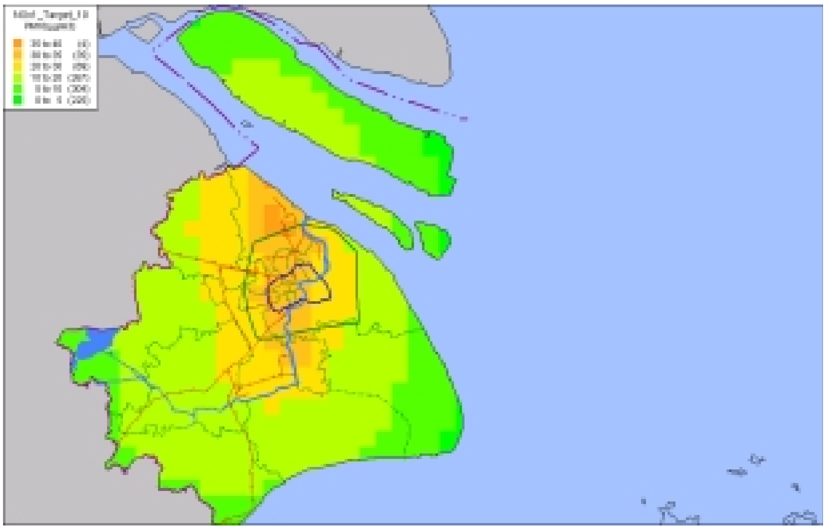

Figure 8.33: *PM_{10} exposure level under SO_2+NOx1 Target scenario of 2010*

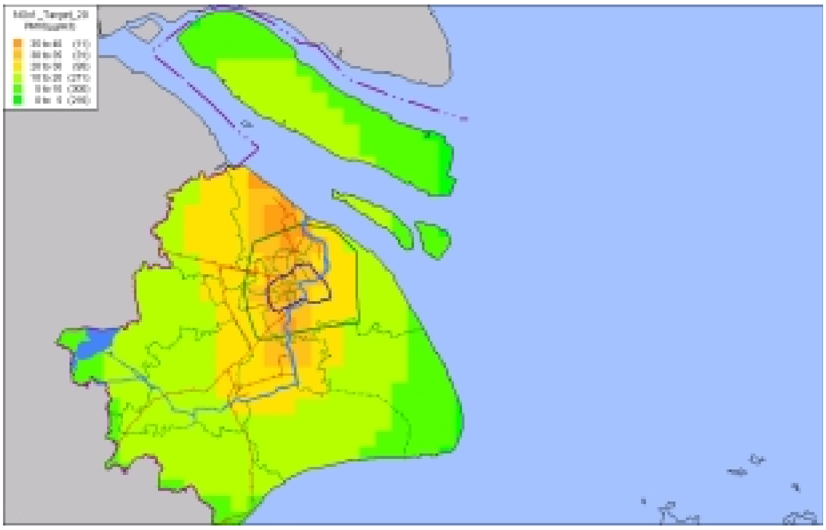

Figure 8.34: *PM_{10} exposure level under SO_2+NOx1 Target scenario of 2020*

(6) SO2+NOx1 Emission Target + CO2 Tax Scenario

Shown in Table 8.11, comparing with NOx Target scenario, no further improvement happened resulting from the policy of CO_2 Tax generally. Comparing with the exposure level in 2000, area below than 0.25 mg/m^3 increased from 11248 km^2 to 12368 km^2 in 2005, 12608 km^2 in 2010 and 13136 km^2 in 2020. Shown in Table 8.12, comparing with NOx Target scenario, exposure level of PM_{10} has been improved further that no more area exceeded 0.035mg/m^3 since 2010. Comparing with the exposure level in 2000, area less than 0.01 mg/m^3 of PM_{10} increased from 8304 km^2 to 18592 km^2 in 2005, 9184 km^2 in 2010 and 9248 km^2 in 2020.

Table 8.11: *Exposure level of SO_2 under SO_2+NOx1 Targe+CO_2 Tax scenario (Unit:km^2)*

SO_2(mg/m^3)	2000	2005	2010	2020
0.135~0.15				
0.12~0.135				
0.1~0.12				
0.08~0.1				
0.06~0.08	320			
0.05~0.06	560	96		
0.04~0.05	704	512	464	160
0.025~0.04	1952	1808	1712	1488
0.015~0.025	2384	2304	2352	2096
0~0.015	8864	10064	10256	11040
average SO_2(mg/m^3) in urban	0.058	0.043	0.040	0.035

Table 8.12: *Exposure level of PM_{10} under SO_2+NOx1 Target+CO_2 Tax scenario (Unit:km^2)*

PM_{10}(mg/m^3)	2000	2005	2010	2020
0.07~0.08				
0.06~0.07				
0.05~0.06				
0.04~0.05				
0.035~0.04	320	560		
0.030~0.035	464	1376	176	96
0.02~0.03	1504	4192	1408	1424
0.01~0.02	4192	4848	4016	4016
0.005~0.01	4768	3808	4864	4768
0~0.005	3536	14784	4320	4480
average PM_{10} (mg/m^3) in urban	0.035	0.032	0.029	0.028

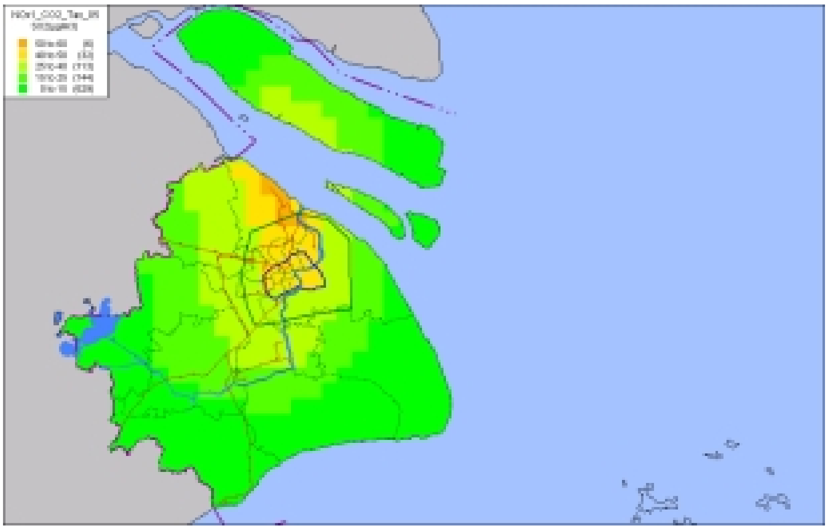

Figure 8.35: *SO_2 exposure level under SO_2+NOx1 Target+CO_2 Tax scenario of 2005*

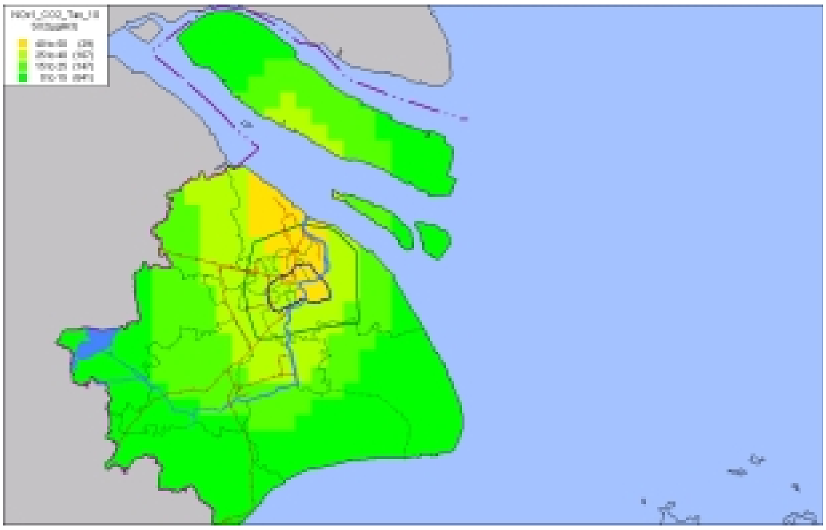

Figure 8.36: *SO_2 exposure level under SO_2+NOx1 Target+CO_2 Tax scenario of 2010*

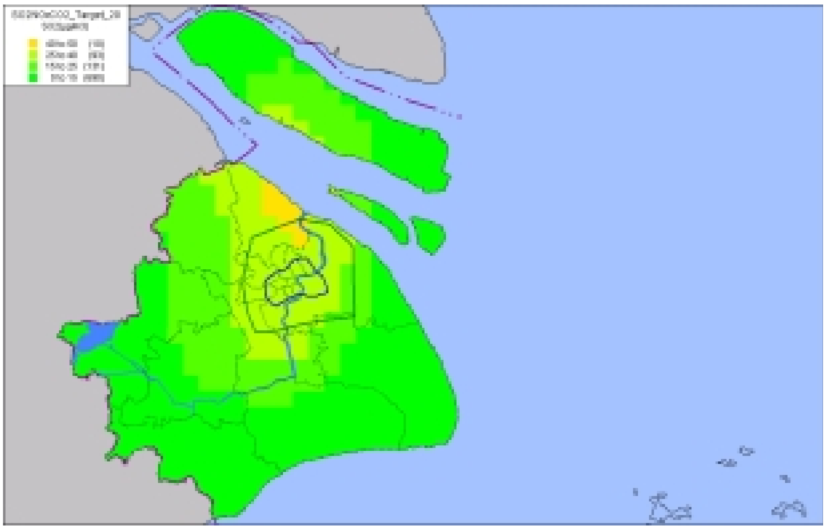

Figure 8.37: *SO_2 exposure level under SO_2+NOx1 Target+CO_2 Tax scenario of 2020*

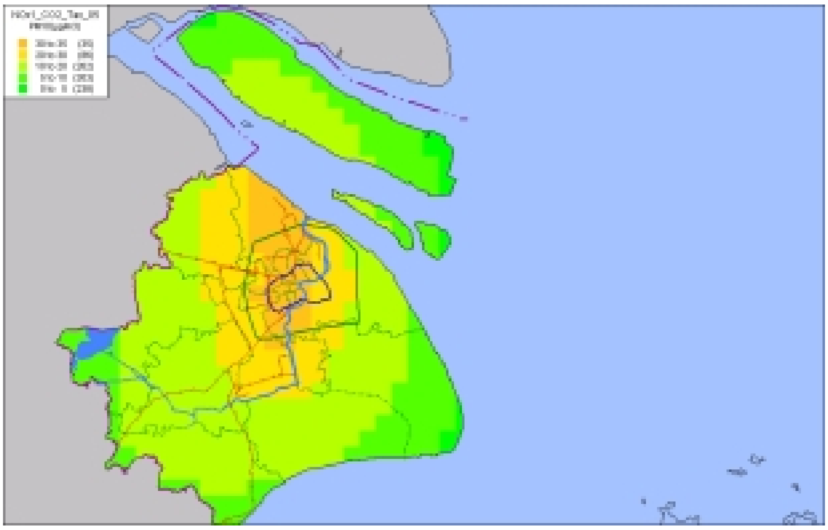

Figure 8.38: *PM_{10} exposure level under SO_2+NOx1 Target+CO_2 Tax scenario of 2005*

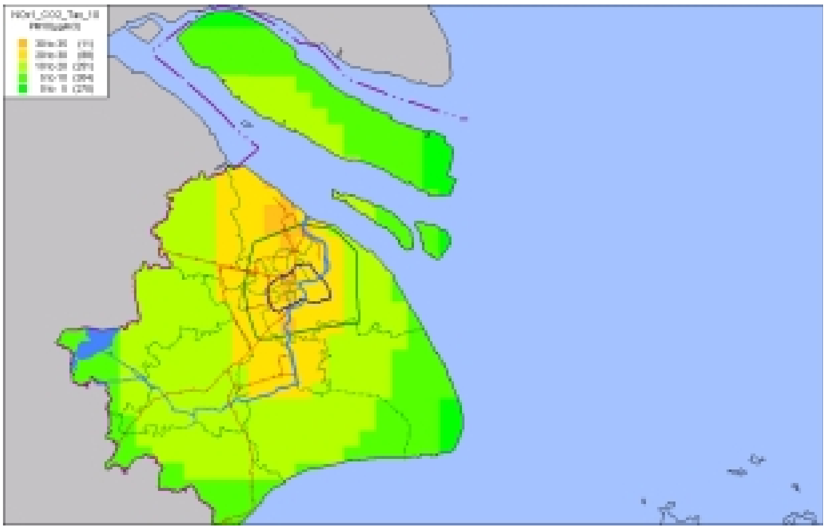

Figure 8.39: *PM_{10} exposure level under SO_2+NOx1 Target+CO_2 Tax scenario of 2010*

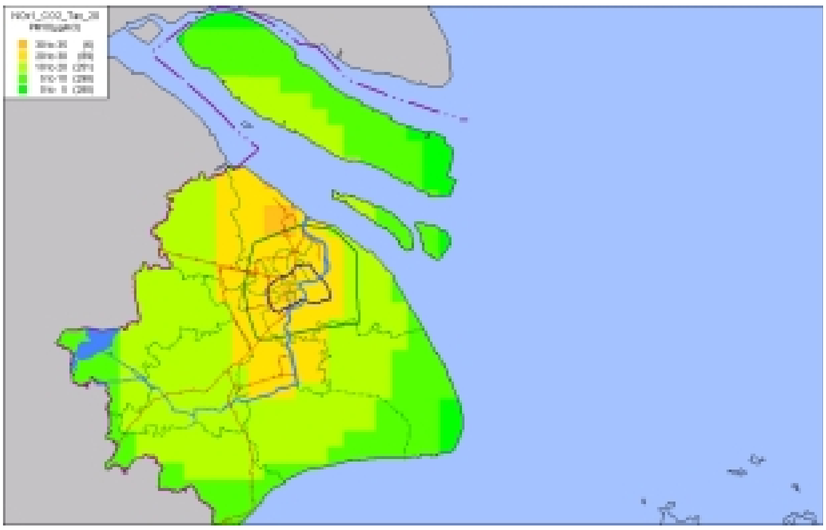

Figure 8.40: *PM_{10} exposure level under SO_2+NOx1 Target+CO_2 Tax scenario of 2020*

8.6 Conclusion

(1) Based on the ATMOS model and principle of transfer matrix, the Shanghai Exposure Level model was developed specially to link the emission prediction of the MARKAL and health benefit analysis. Exposure level of SO_2 and primary PM_{10} were provided for 5 scenarios of 2005, 2010 and 2020, including the Base Case Scenario, Energy Efficiency Improvement Scenario (EFF), Expanding Gas Use Scenario (GAS2), SO_2 Emission Target Scenario, SO_2+NOx1 Emission Target Scenario, SO_2+NOx1 Emission Target + CO_2 Tax Scenario.

(2) Base Case Scenario: Comparing with 320 km^2 exceeding the grade II criteria of SO_2 (national standard GB3095-1996: 0.06 mg/m^3) in 2000, the number was increased to 1184 km^2 in 2005, 1600 km^2 in 2010 and 2448 km^2 in 2020. Additional area of 608 km^2 exceeded grade I of PM_{10} (national standard GB3095-1996: 0.04 mg/m^3) in 2005, which increased to 928 km^2 in 2010 and 2080 km^2 in 2020.

(3) Energy Efficiency Improvement Scenario: Comparing with Base Case Scenario, area exceeding standard of SO_2 was reduced by 224 km^2 in 2005, 336 km^2 in 2010, and 400 km^2 in 2020. Area exceeding standard of PM_{10} was reduced by 432 km^2 in 2005, 528 km^2 in 2010 and 944 km^2 in 2020.

(4) Expanding Gas Use Scenario: Comparing with EFF scenario, area exceeding standard of SO_2 was reduced by 784 km^2 in 2005, 1136 km^2 in 2010 and 2000 km^2 in 2020. Area exceeding standard of PM_{10} was reduced by 160 km^2 in 2005, 224 km^2 in 2010 and 448 km^2 in 2020.

(5) SO_2 Emission Target Scenario: Contributing to policy of total amount control on SO_2, no more area exceeded the standard of SO_2 since 2005. Comparing with the GAS2 scenario, no more area exceeding standard of PM_{10} in 2005, which was reduced by 112 km^2 in 2010 and 16 km^2 in 2020.

(6) SO_2+NOx1 Emission Target Scenario: Comparing with SO_2 Target scenario, concentration of SO_2 is decreased further and no more area exceeded the standard of PM_{10} since 2005.

(7) SO_2+NOx1 Emission Target + CO_2 Tax Scenario: Quality of SO_2 and PM_{10} in ambient air are improved continuously, the concentration of SO_2 and PM_{10} in urban decreased from 0.058 mg/m^3 and 0.035 mg/m^3 in 2000 to 0.043 mg/m^3 and 0.032 mg/m^3 in 2005, to 0.040 mg/m^3 and 0.029 mg/m^3 in 2010, further to 0.035 mg/m^3 and 0.028 mg/m^3 in 2020.

9. Health Effect Analysis

9.1 Introduction

The previous section of this report "Integrated Assessment of Energy Option and Health Benefit in Shanghai" has indicated that energy options in Shanghai could not only reduce the emission of greenhouse gases (GHGs), but also bring about ancillary benefits from various GHGs mitigation scenarios, such as improvement of local air quality and the subsequent decrease of human exposure level to air pollution. As part of the integrated assessment, the present section is aimed at providing a quantitative estimate of the health effects (benefit/damage) associated with various energy option scenarios in Shanghai following the framework shown in Figure 9.1.

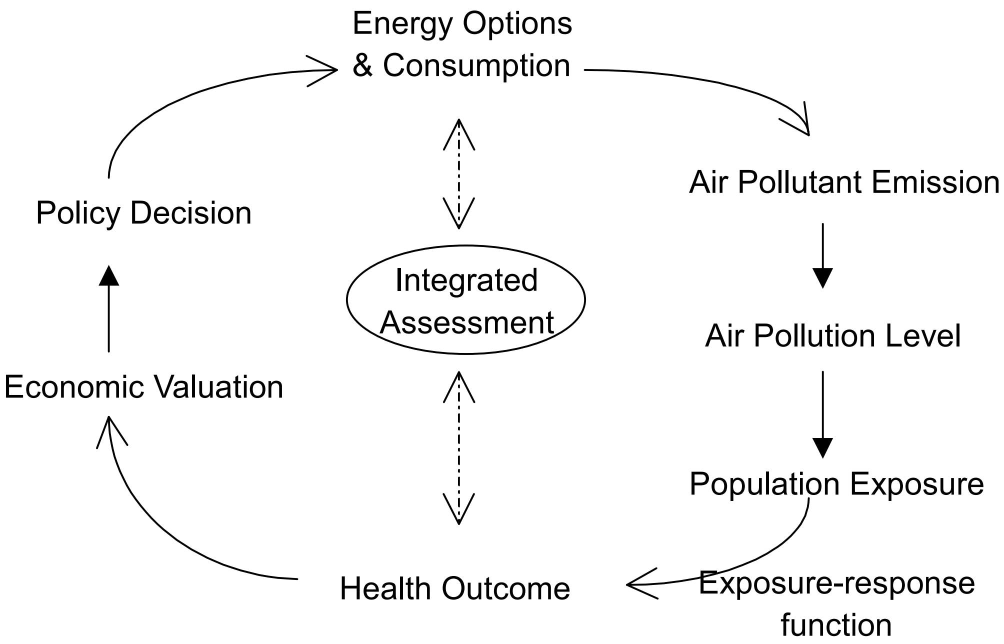

Figure 9. 1 ***Framework linking energy options and health effects***

Numerous epidemiologic studies during the past 10-20 years confirm that exposure to ambient air pollution contributes to both mortality and morbidity, whether worldwide or in China[1,2,3,4,5]. Among them, some effects may be related to short-term exposure[1,2,3], others to contributions of long-term exposure[4,5]. Although the underlying mechanisms have not yet been fully explained, epidemiologic evidence suggests that outdoor air pollution is a contributing factor of mortality and morbidity. State-of-the-art epidemiologic research has found consistent and coherent association between air pollution and various health outcomes, which ranged from reduced lung function, respiratory symptoms, chronic bronchitis to mortality[6].

Within the framework of risk assessment, it is important to quantify these health effects associated with exposure to ambient air pollution. Recent advance in epidemiologic methods and studies has made the quantitative health impact assessment associated with air pollution possible. In fact, several impact assessment studies have been initiated and completed by local, national, and international organizations and agencies[7,8,9].

The goal of the present study is to give an estimate of health effects of air pollution under various energy option scenarios in Shanghai.

9.2 Health Effect Analysis

9.2.1 General approach

The approach used in this analysis was based on the quantitative risk assessment framework. Since most of the epidemiologic studies linking air pollution and health endpoints are based on a relative risk model in the form of Poisson regression, as shown in Figure 9.2, the cases at a given concentration C, could be given by:

$$\mathbf{E = \exp(\beta \times (C\text{-}C_0)) \times E_0} \qquad \textbf{(1)}$$

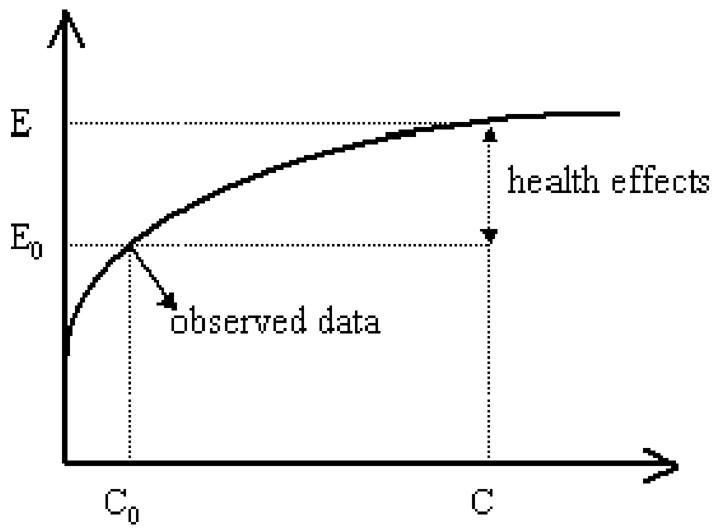

Figure 9.2 ***Model to derive number of cases under different scenarios***

In equation (1), C and C_0 are the air pollutant concentration under one specific scenario and baseline scenario, respectively, and E and E_0 are the corresponding health effect cases under concentration of C and C_0. The health effect (benefit/damage) under the scenario with respect to baseline scenario is the difference between E and E_0. The value could be obtained if the following data components are available: exposure-response functions (β), population exposure levels (C and C_0), and baseline rate (E_0). The following sections explained each of these components in detail.

The final results of this analysis were given as the comparison of health effects under one specific scenario with respect to BC scenario in the near future.

9.2.2 Human exposure assessment

(1) Time periods and scenarios

The year 2000 was selected as the base period in this analysis. Air quality changes in 2010 and 2020 were estimated under the following scenarios: BC, EFF, GAS 2, SO_2, $SO_2 + NO_x$1 target, and $SO_2 + NO_x$1 target + CO_2 tax. The contents and the subsequent air quality changes under each scenario were described in detail in the previous section of the final report by Chen Changhong et al.

(2) Resolution of exposure assessment

In this assessment, we divided Shanghai into four kilometers by four kilometers grid cells, and estimated the changes in population exposure level and incidence of adverse health effects in each cell. Total health effects associated with air pollution in Shanghai were equal to the sum of grid-cell-specific changes.

(3) Air pollutants

Ambient air pollution consists of a mix of different pollutants. For Shanghai, TSP, SO_2 and NO_x are major air pollutants and were routinely monitored up to July 1, 2000. PM_{10} and NO_2 have taken the place of TSP and NO_x as the indicator pollutants after this date.

In most of the epidemiologic studies, it is impossible to attribute the health effects to one specific pollutant. A problem called "double counting effect" would arise when the health effects associated with several pollutants simultaneously are simply added up for assessment. In the current study, PM_{10} was selected as an indicator of "total air pollution" to estimate the relevant health effects, since there has been strong epidemiologic evidence to support the association between PM_{10} and adverse health effects.

(4) Population under study

All people living in the whole city of Shanghai were considered as the exposed population in this analysis. An estimate of the distribution of Shanghai population in each grid cell was then made for the assessment. However, it is impossible to have official data on the population number in each 4km X 4km cell in Shanghai. An alternative approach based on pooling of population density in community within each grid cell adjusted to geography size of the portion of communities in each grid cell was adopted. In addition, population number in each grid cell was assumed to grow at the same rate in the near future, and population age distribution in each cell to be identical.

9.2.3 Selection of health outcomes

Air pollution-related effects were summed up on a series of health outcomes in different levels, ranging from morbidity to mortality changes. The following criteria were used in selecting health outcomes for this analysis:

1. Studies conducted in China were preferred. When those widely accepted health outcomes associated with air pollution were not available in Chinese literatures, e.g., long-term mortality, the results from international literatures were then used.

2. Quantitative exposure-response relationships between air pollutants and health outcomes had been established (in the form of either slope or relative risk).

3. Sub-clinical effects, such as lung functions changes, were not included in the assessment, because it is difficult to translate them into long-term health impact & monetary values based on current knowledge.

4. The baseline data of selected outcome should be available in Shanghai or China. For example, the endpoint of restricted activity days (RADs), which is an important endpoint in many air pollution-related health impact assessment, was not included in the present analysis, because of the lack of the baseline RADs data either in Shanghai or in China.

Based on the above criteria, the selected health outcomes associated with PM_{10} exposure were as follows:

- **Mortality**
  - ✓ Short term
  - ✓ Long term

- **Morbidity**
  - ✓ Chronic bronchitis
  - ✓ Hospital admission (respiratory and cardiovascular systems)
  - ✓ Outpatient visits (internal medicine and pediatrics)
  - ✓ Other illness (acute bronchitis, asthma attack)

9.2.4 Exposure-response functions

Exposure-response functions link air quality changes and heath outcomes. The preference for this analysis was to select C-R functions from Chinese studies whenever they were available. Only when the selected endpoints could not be found in Chinese literatures, the results of international peer-reviewed literatures were used.

If there were several studies describing the C-R function for the same health endpoint, we used the pooled estimate to get the mean and 95 percent confidence interval (CI) of the coefficient. This meta analysis method was based on the variance weighted average across the results of studies with available quantitative effect estimates (coefficients or relative risks). Studies with lower standard errors had more weight in the resulting joint estimate[10].

Although PM_{10} was selected as the indicator of air pollution in this analysis, some studies depended on other measures of particulate matter (TSP, $PM_{2.5}$) for exposure assessment. Therefore, if necessary, the following conversion were applied for different particulate matter indicators[11]:

$PM_{10}=TSP\times 0.65$ and $PM_{2.5}=PM_{10}\times 0.65$

9.2.5 Baseline incidence data

In this analysis, the year 2000 was selected as the baseline period for our assessment. The baseline incidence data for various health outcomes were collected from actual data of Shanghai or proxy data from other regions of China or at the national level. These data were usually in the form of annual incidence rate.

9.3. Results

9.3.1 Population exposure assessment

By the end of 2000, Shanghai had a population of 13.13 millions according to population household registration, accounting for about 1% of the nation's total[12]. In 2010 and 2020, the total population number is expected to reach 14.00 and 14.30 millions respectively[13].

Table 9.1 shows the age distribution for Shanghai residents according to "Survey on 1% Change of Population in China" conducted in 1995[14].

Table 9.1 *Percentage of population by age groups in Shanghai*

Range	Percent (%)	Range	Percent (%)
0-4	3.60	55-59	4.23
5-9	6.52	60-64	5.30
10-14	7.02	65-69	4.42
15-19	5.79	70-74	3.33
20-24	6.03	75-79	2.07
25-29	6.59	80-84	1.07
30-34	9.09	85-89	0.40
35-39	11.75	90-94	0.12
40-44	10.59	95-99	0.01
45-49	7.36	=>100	0.0027
50-54	4.71	Total	100

Combining the air quality level and population number in each cell, we estimate population exposure level to PM_{10} under different scenarios in Shanghai. Tables 9.2-9.3 summarize the percent of population exposed to different levels of PM_{10} in 2010 and 2020 respectively.

Table 9.2 ***Percent of population exposure to PM10 level under different scenarios in 2010(%)***

PM_{10} level (mcg/m^3)	BC	EFF	GAS2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
<5	—	—	0.1	0.1	0.4	0.8
10-15	6.4	6.8	9.2	9.8	12.5	13.3
15-20	8.2	8.5	11.1	10.8	8.3	7.9
20-25	8.3	8.0	5.1	5.5	6.1	8.2
25-30	4.4	4.2	5.3	5.8	13.0	44.6
30-35	3.3	4.5	9.1	12.6	51.6	15.6
35-40	4.8	5.2	35.7	38.2	0.6	—
40-45	7.0	11.1	19.9	12.5	—	—
45-50	18.1	31.5	—	—	—	—
50-55	37.5	17.9	—	—	—	—
Total	100	100	100	100	100	100

Table 9.3 ***Percent of population exposure to PM10 level under different scenarios in 2020(%)***

PM_{10} level (mcg/m^3)	BC	EFF	GAS2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
<5	—	—	—	—	0.3	0.9
10-15	0.3	0.5	2.9	2.9	6.9	9.6
15-20	2.6	2.9	7.6	7.6	12.8	13.8
20-25	5.1	5.6	9.9	10.0	7.9	7.6
25-30	5.7	6.2	6.5	6.5	5.7	10.6
30-35	6.8	6.4	4.6	4.7	12.1	50.1
35-40	5.2	5.4	4.2	5.0	44.4	7.4
40-45	3.0	2.7	8.4	7.5	9.9	—
45-50	2.9	2.9	18.8	19.8	—	—
50-55	2.4	3.3	37.1	36.0	—	—
55-60	4.0	3.9	—	—	—	—
60-65	2.4	8.9	—	—	—	—
65-70	12.4	16.0	—	—	—	—
70-75	13.3	35.3	—	—	—	—
>75	33.9	—	—	—	—	—
Total	100	100	100	100	100	100

It should be emphasized that the PM_{10} level in Tables 9.2-9.3 are much lower than the actual concentration in Shanghai, because in the present study, only the PM_{10} from the source of energy consumption was assessed. Those from other sources, such as natural sources, construction sites etc, were excluded.

In 2000, the population-weighted average exposure concentration of PM_{10} due to energy consumption in Shanghai was 27.66 mcg/m^3. Figure 9.3 shows the effect of different energy scenarios on the population-weighted PM_{10} concentration in 2005, 2010 and 2020, respectively. It is clear that the “SO2 + NOx1 target + CO2 tax” scenario could have the most obvious effect on the reduction of PM_{10} concentration.

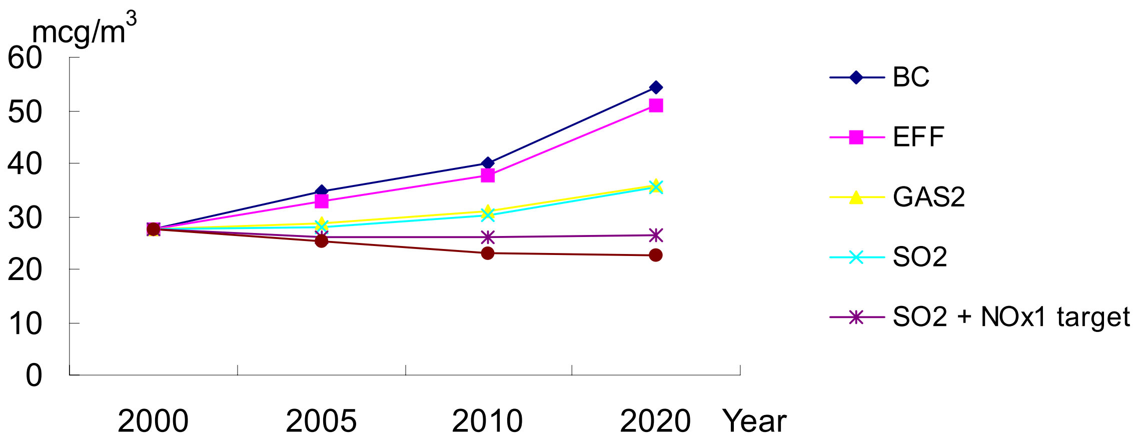

Figure 9.3 ***Population-weighted average PM_{10} concentration under different scenarios***

9.3.2 Health effects

Tables 9.4-9.5 summarize the PM_{10} exposure-response coefficients (mean and 95% CI) and the baseline rates of selected health outcomes in the analysis. The excess cases in each scenario with respect to BC scenario are computed based on the change of population exposure levels to PM_{10} under each scenario, exposure-response functions, and baseline rates for the health outcomes. Tables 9.6-9.7 show the mean and 95% CI of the results in 2010 and 2020, respectively.

Table 9.4 ***Summary of exposure-response coefficients used in the analysis***

Health Outcome	Mean (95%CI)	Source
Long-term mortality (adult≥30)	0.00430 (0.00260, 0.00610)	Dockery et al[4] Pope et al[5]
Chronic bronchitis (all ages)	0.00450 (0.00127, 0.00773)	Ma et al[15] Jin et al[16]
Short-term mortality (all ages)	0.00028 (0.00010, 0.00046)	Xu X et al[17] Xu Z et al[18]
Respiratory hospital admission (all ages)	0.00130 (0.00010, 0.00250)	Zmirou et al[19] Wordley et al[20] Prescott et al[21]
Cardiovascular hospital admission (all ages)	0.00130 (0.00070, 0.00190)	Wordley et al[20] Prescott et al[21] Poloniecki et al[22]
Outpatient visits- internal medicine (all ages)	0.00034 (0.00019, 0.00049)	Xu et al[23]
Outpatient visits-pediatrics (all ages)	0.00039 (0.00014, 0.00064)	Xu et al[23]
Acute bronchitis (all ages)	0.00550 (0.00189, 0.00911)	Jin et al[16]
Asthma attack (children<15 years)	0.00440 (0.00270, 0.00620)	ROEMER ET AL[24] Segala et al[25] Gielen et al[26]
Asthma attack (adults≥15 years)	0.00390 (0.00190, 0.00590)	Dusseldorp et al[27] Hiltermann et al[28] Neukirch et al[29]

Table 9.5 ***Summary of the baseline rate in the analysis (per person)***

Health Outcomes	Frequency	Source
Mortality (adult≥30)	0.01077	Shanghai Municipal Bureau of Public Health[30]
Chronic bronchitis (all ages)	0.01390	China Department of Health[31]
Mortality (all ages)	0.00728	Shanghai Municipal Bureau of Public Health[30]
Respiratory hospital admission (all ages)	0.01240	Shanghai Municipal Bureau of Public Health[30]
Cardiovascular hospital admission (all ages)	0.00850	Shanghai Municipal Bureau of Public Health[30]
Outpatient visits- internal medicine (all ages)	3.26000	Shanghai Municipal Bureau of Public Health[30]
Outpatient visits-pediatrics (all ages)	**0.30000**	Shanghai Municipal Bureau of Public Health[30]
Acute bronchitis (all ages)	0.39000	Wang et al[32]
Asthma attack (children<15 years)	0.06930	Ling et al[33]
Asthma attack (adults≥15 years)	0.05610	Ling et al[33]

Table 9.6 ***Health benefits in different scenarios with respect to BC Scenario in Shanghai in 2010 (mean and 95% CI)***

Endpoint	EFF	GAS 2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
Premature death	647 (402, 858)	2937 (1842, 3859)	3275 (2056, 4299)	4538 (2861, 5933)	5472 (3460, 7132)
Chronic bronchitis	1315 (406, 1995)	5964 (1872, 8905)	6649 (2091, 9912)	9210 (2918, 13630)	11100 (3536, 16340)
Respiratory Hospital admission	377 (32, 693)	1740 (146, 3176)	1943 (164, 3545	2712 (229, 4934)	3286 (278, 5967)
Cardiovascular Hospital admission	260 (141, 372)	1197 (654, 1712)	1336 (730, 1911)	1865 (1020, 2663)	2260 (1238, 3224)
Outpatient visits (internal medicine)	27080 (15320, 38620)	125400 (71030, 178800)	140200 (79380, 199800)	196000 (111100, 279300)	237900 (134800, 338900)
Outpatient visits (pediatrics)	2807 (1010, 4571)	13000 (4686, 21150)	14530 (5237, 23620)	20320 (7328, 33020)	24660 (8896, 40050)
Acute bronchitis	49490 (19440, 71710)	223500 (89380, 318100)	249000 (99800, 353900)	344200 (139100, 485100)	414200 (168400, 580400)
Asthma attack	1508 (843, 2076)	6858 (3872, 9354)	7649 (4323, 10420)	10610 (6021, 14390)	12790 (7285, 17300)

Table 9.7 ***Health benefits in different scenarios with respect to BC Scenario in Shanghai in 2020 (mean and 95% CI)***

Endpoint	EFF	GAS 2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
Premature death	1265 (765, 1726)	6834 (4203, 9161)	6958 (4280, 9325)	9807 (6085, 13030)	11130 (6934, 14730)
Chronic bronchitis	2580 (758, 4115)	13910 (4212, 21520)	14160 (4291, 21900)	19940 (6138, 30370)	22620 (7015, 34230)
Respiratory Hospital admission	704 (58, 1318)	3918 (326, 7244)	3991 (332, 7377)	5707 (477, 10490)	6522 (547, 11960)
Cardiovascular Hospital admission	485 (262, 702)	2694 (1462, 3879)	2744 (1489, 3951)	3924 (2136, 5633)	4485 (2444, 6429)
Outpatient visits (internal medicine)	49850 (28150, 71270)	279600 (158100, 399200)	284900 (161100, 406600)	409200 (231500, 583800)	468600 (265200, 668300)
Outpatient visits (pediatrics)	5173 (1855, 8453)	29000 (10420, 47280)	29540 (10620, 48160)	42430 (15270, 69100)	48590 (17500, 79080)
Acute bronchitis	98520 (36640, 151000)	526400 (202500, 780000)	535900 (206300, 793500)	751300 (294200, 1094000)	850800 (335700, 1230000)
Asthma attack	2937 (1596, 4165)	15910 (8798, 22160)	16200 (8961, 22550)	22860 (12760, 31540)	25960 (14560, 35680)

9.4 Conclusion

Energy options could have significant impact on the health status for Shanghai residents. Compared with BC scenario, implementation of various energy scenarios in Shanghai could prevent 647-5,472 and 1,265-11,130 PM_{10}-related avoidable deaths (mid value) in 2010 and 2020, respectively.

For the morbidity endpoints, adopting various energy scenarios could also prevent 1,315-11,100 new cases of chronic bronchitis, 377-3,286 cases of respiratory hospital admission, 260-2,260 cases of cardiovascular hospital admission, 27,080-237,900 internal-medicine outpatient visits, 2,807-24,660 pediatrics outpatient visits, 49,490-414,200 cases of acute bronchitis, and 1,508-12,790 asthma attacks (mid values) in 2010, respectively. In 2020, the numbers are expected to increase to 2,580-22,620 new cases of chronic bronchitis, 704-6,522 cases of respiratory hospital admission, 486-4,485 cases of cardiovascular hospital admission, 49,850-468,600 internal-medicine outpatient visits, 5,173-48,590 pediatrics outpatient visits, 98,520-850,800 cases of acute bronchitis, and 2,937-25,960 asthma attacks (mid values).

9.5 Discussion

1. In the present analysis, we only focused on those health outcomes that could be quantitatively estimated and translated into monetary values. Some endpoints, e.g. sub-clinical symptoms, were not included in this analysis, although there is evidence for an association between them and

ambient air pollution exposure.

Among all endpoints associated with air pollution, mortality is the most important one from both health and economic perspective[kan1]. In the present analysis, both short-term and long-term changes were included. Conceptually, the impact of air pollution on mortality is a combination of acute as well as cumulative chronic effects. In the case of short term effects, which were described in a number of time series studies and several new studies using case cross-over design, air pollution levels of a given day or short period of days may trigger an increase of deaths within days or weeks. However, the associations found between day to day variations in mortality and air pollution may, for example, represent a "harvesting" effect, i.e., advancement of death by a few days or weeks in subjects already about to die from other causes anyway. Clearly, such effects would not lead to discernible effects of long-term exposure to air pollution on life expectancy in the population. That is, the short-term effects of air pollution on mortality only capture a small part of air pollution-related cases34. Therefore, in this analysis, we calculated the effects both from short term and long-term exposure to air pollution, which should provide a more complete picture of the impact.

2. For population exposure assessment in this analysis, we only focused on PM10 as the indicator of total air pollution, which would probably underestimate the health effects attributable to air pollution. Although PM10 may be a good indictor of air pollution, there is clear evidence that other pollutants may be of independent health effects. One such example is ozone as an indicator of oxidant pollution. In Shanghai, however, no monitoring data on ozone exist so far. In addition, there is an increasing discussion whether particle number or particle surface area correlates better to adverse health outcomes than particle mass.

3. A relative part of the exposure-response functions we adopted in this analysis were not available in Chinese studies. So we had to rely on international studies, conducted mostly in U.S. and Western Europe. This raises the question of transferring the results from a developed country to a developing one. For example, compared to the studies in U.S. and Europe, the Chinese studies generally reported lower coefficients for the exposure-response relationships between air pollution and adverse health effects. This is probably due to different levels of air pollution, local population sensitivity, age distribution and especially different air pollutant components. For instance the composition of motor vehicle fleet in Western Europe and USA, where most of the epidemiological studies were performed, differs substantially from that in China. This, together with other differences as the widespread use of coal in China, implies that the air pollution mixture differs substantially between China and the areas where most epidemiologic studies were conducted. Therefore, conceptually, when exposure-response functions from developed countries were applied to other regions, for example - Shanghai, they should be revised, taking account of local conditions, such as physical (diameter, etc.) and chemical (components) character of particles, social-economical status of local populations, etc. However, no reference data are available for such a revise. Until exposure-response functions derived locally become available, this will probably be the weakest part of the analysis.

4. Another important aspect that may strongly influence the impact assessment was baseline rate of selected health endpoints. Whereas for mortality the data source may be considered accurate, frequency measures of morbidity and data on health-care systems have to be considered as estimates with some inherent uncertainties.

In addition, the baseline rates were assumed to be the same in all cells in [KH2]the present analysis; however, there should be some difference in the geographical distribution of the number, for the obvious disparity of health status of residents living in rural and urban areas of Shanghai. For example, in the urban areas of China, the incidence rate of chronic bronchitis was about 18.72 ‰, while the number decreased to 10.94‰ in the rural areas of China31. Therefore, it is recommended that a more in-depth study should be conducted to distinguish the baseline rates in rural and urban areas, respectively.

5. In the calculation of public health impact of ambient air pollution, it is crucial to decide what level of exposure may be considered as the threshold level or "reference exposure". Threshold concentration means that below such a concentration, there is no observed adverse health damage. In formula 1 and the calculation process mentioned above, we assumed that there is no threshold in the air pollution–related health effects. If there is a threshold, as shown in Figure 9.4, formula 1 will become

$$E = \exp(\beta \times (\max(C, Ct)-\max(C0-Ct))) \times E0 \qquad (2)$$

in which Ct is the threshold level.

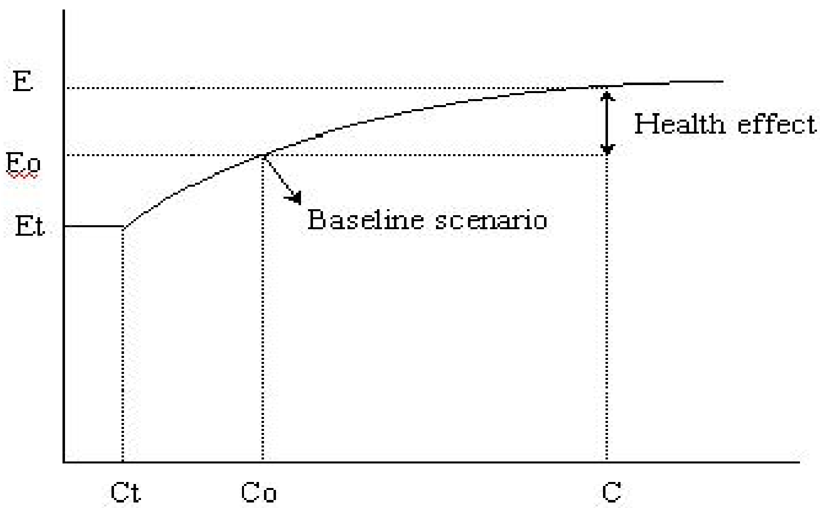

Figure 9.4 ***Model to derive number of cases with threshold***

Normally, there are many different recommendations as to where to impose a threshold in air pollution-related health impact assessment, which include: no threshold (or zero threshold), natural background level, the lowest observed level in epidemiological studies and legal/policy established standards (such as the US EPA NAAQS and China National Air Quality Standards). The possible existence of an effect threshold is a very import scientific issue for air pollution-related health impact assessment. However, currently there is no scientific basis for setting a particular threshold for PM_{10} for the effects considered in this analysis. Therefore, in the present analysis no threshold was applied for modeling health effects. However, we could explore the potential impact with various threshold assumptions for sensitivity analysis.

6. Basically, the approach used in this study is based on health risk assessment procedures. As an intrinsic character of risk assessment, uncertainly exists in each step of this analysis. For example, the parameters in the analysis, such as coefficients of exposure-response functions, were treated as distributions rather than constants in the analysis. Therefore, to deal with the uncertainty in the analysis, we performed Monte Carlo simulation in the Aanlytica® modeling environment (Lumina Decision System), and the final report was presented as a range of impact rather than an exact point estimate.

7. Despite of the uncertainties described above, our analysis still emphasis the need to consider air pollution-related health effects as an important impact of energy options in Shanghai. In a century moving toward sustainable development and health, close collaboration between public health and energy policy will enhance success in preventing avoidable health hazards. Further development in health impact assessment method is needed, especially in the area of dealing with uncertainty, transference of exposure-response functions, and more common health indicators such as DALYs etc. All these will be most fruitfully done with close collaboration between air pollution modelers, epidemiologists, economists, and policy makers.

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10. Economic Valuation Of Health Outcomes Associated With Air Pollution Under Various Energy Scenarios in Shanghai

10.1 Introduction

Valuation of health outcomes is a critical component in assigning the social cost of air pollution, for it allows the performance of cost-benefit analysis and provides a basis for setting priority for next-step actions. The goal of this analysis is aimed at putting monetary values on the health outcomes that were estimated in Part One and Part Two of this report.

There are several existing methods that could be used to estimate the monetary values of health outcomes associated with air pollution. The approach of wiliness-to-pay (WTP) measures how much the concerned individuals are ready to pay in order to improve their own security or that of other people. The main advantage of WTP relies in its foundation on the individual viewpoint and wishes of the concerned population; therefore, the choice of WTP better meets the requirement of welfare economics. The main difficulty of the WTP approach consists of obtaining reliable and correct empirical estimation[i].

A variety of valuation techniques have been used to measure the WTP value: labor-market (hedonic) studies, the contingent valuation method (CVM), and various types of market-based analysis. Labor-market analysis studies generally attempt to infer the compensation required in exchange for the increased risk associated with particular occupations while standardizing for all other attributes of the job and the worker. Contingent Valuation method (CVM) uses survey information to determine what people are prepared to pay to reduce the likelihood of premature death or certain diseases. The market-based approach attempts to infer the WTP for reductions in risk from the purchase of goods whose only purpose is to reduce the risks confronting an individual[1].

For mortality valuation, the most commonly applied approach is the value of a statistical life (VOSL). The VOSL measures the value of given reduction in risk and an individual's WTP to reduce the risk, relying on wage and occupational risk tradeoff data or the results of CVM studies. The result of applying this methods is not the value of an identifiable life, but instead the value of reducing fatal risks in a population[1].

There is also a substantial literature on the valuation of health outcomes that relies on the human capital approach (HCA) and cost of illness (COI). The Human Capital approach considers individuals as units of human capital that produce goods and services for society; therefore, HCA assesses the costs of a premature death by counting the discounted values of future production which the "victims" could have generated if they had not died prematurely. Cost of Illness (COI) approach applies to morbidity and is consistent with human capital approach. COI estimates the medical treatment costs plus the loss of production due to a possible incapacity to work. The main advantage of these two approaches lies in their simple and transparent calculation concept, subsequently resulting in a higher social acceptance. The HCA and COI, however, neglect a basic principle of the welfare economics theory, according to which each valuation of positive and negative impacts has to be based on the variations in the utility of the concerned individuals. Actually, HCA and COI are not entirely unconnected with WTP. In particular, theory shows that HCA/COI provides a lower bound estimate of WTP[ii].

As for the present analysis, the preferred approach is based on individual WTP for risk reduction, while COI was also calculated as an alternative estimate for some morbidity endpoints due to the absence of existing WTP literatures on these endpoints.

10.2 Methods

10.2.1 General approach

The effect of air pollution on mortality was assessed by using the *value of a statistical life* (VOSL). The literature on the VOSL, or on willingness to pay to avoid a statistical premature death, however, is mainly from the United States. Due to limited time and budget, the present analysis relied on a contingent valuation study, which was conducted in Chongqin, China, for the estimate of Shanghai VOSL. The effect of income on the VOSL was also taken into account for the value transfer.

For different endpoints of morbidity, since there are no WTP studies so far on these endpoints in China, we took an alternative approach to infer the WTP value from those used by U.S. EPA after conversion if data were available. The COI approach was also employed for valuing the endpoints of hospital admission and outpatient visits due to paucity of relevant WTP literature.

The unit values for various endpoints are expected to update annually using a constant growth in per capita income of 4%, which was estimated according to Shanghai gross domestic product (GDP) growth scenario described by Chen Changhong et al[iii] and the relationship between resident income and GDP growth in China[iv].

The value of a change in the incidence of a given adverse health outcome was calculated as the change in incidence (e.g. the number of avoidable deaths) multiplied by the unit monetary value (the value of a single case avoided). Since both health outcomes and unit values are distributions rather than constants, we performed the Monte Carlo simulation to calculate the economic benefits on the Analytic® environment.

10.2.2 Valuation of premature death associated with air pollution

The present analysis was mainly based on the result of a study on the WTP for a reduction in mortality risk related to air pollution, which was conducted in Chongqin, China[v]. In the study, Wang Hong et al reported an average WTP for saving a statistical life US$34,750 using contingent valuation method (CVM). The marginal effect of income on WTP value was also reported as: with annual income increase of $145.8, the marginal increase for saving a statistical life in Chongqin was $14,550. Therefore, taking the annual income difference between Chongqin and Shanghai residents into account, which were $495.7[5] and $1234.5[vi] respectively, we did a conversion based on Chongqin's coefficient between marginal WTP and income, and got an estimate of US$108,500 for the VOSL in Shanghai. It should be emphasized that the annual income of $1234.5 is estimated from all urban and rural residents living in Shanghai, not just those living in urban districts. The different incomes of urban and rural residents have been considered in the conversion process.

10.2.3 Valuation of morbidity change associated with air pollution

Air pollution also affects human morbidity, and the valuation of illness and disability is important for assessing the total social costs of air pollution. The literature on WTP to avoid morbidity outcomes is limited in scope and is based mostly on U.S. data. An alterative that is often used for valuing morbidity is the cost of illness (COI), which uses estimates of the economic costs of health care and lost output up to recovery or death. These comprise the sum of direct costs (hospital treatment, medical care, lost wages, and so on) and indirect costs. The present analysis uses either the WTP approach (where estimates are available) or the COI approach (where WTP estimates are lacking) to value the morbidity outcomes associated with air pollution.

(1) Valuation of chronic bronchitis

Chronic bronchitis is the only air pollution-related morbidity endpoint that may last from the beginning of the illness throughout the rest of the individual’s life. Two U.S. studies provide estimates of WTP to avoid chronic bronchitis, using the CV method: Viscusi et al[vii] and Krupnick and Cropper[viii]. We followed the approach used in the U.S. EPA “*The Benefits and Costs of the Clean Air Act 1990 to 2010*”[ix] to establish the best estimate from these two studies. Using distributions of the WTP components mentioned above, the Monte Carlo analysis generated a mean of US$ 260,000 for WTP to avoid an air pollution-related case of chronic bronchitis (in 1990 dollars).

Based on the risk-risk and risk-dollar trade-off methods that were used by Viscusi et al[7] for WTP estimate, it is recommended that a constant ratio should be kept between the VOSL and WTP to avoid a case of chronic bronchitis[x]. Since U.S. EPA uses a VOSL of US$4.8 million (in 1990 dollars), whereas this study adopts a lower estimate of US$ 108,500 in Shanghai, we downsized the WTP to avoid a new case of chronic bronchitis in this analysis accordingly and used the mean value of US$ 6,050 (in 2000 US$) in our calculation.

(2) Valuation of acute morbidity outcomes

- **Hospital admissions and outpatient visits**

Due to the paucity of WTP literature on the endpoints of hospital admissions and outpatient visits, we relied on the COI approach for the valuation of those endpoints. The direct cost of morbidity can be divided into two categories: medical expenditure for treating illness; and lost wages during days spent in bed, days missed from work, and other days when activities are significantly restricted due to illness. The indirect cost components, such as averting behavior, intangible costs, etc, were neglected.

The medical treatment cost of hospital admissions was calculated based on the average duration of a hospital admission and the average daily cost in Shanghai[xi]. The per capita lost wages were estimated according to the duration time and the income per person in Shanghai[6].

- Acute bronchitis and asthma attack

For the endpoints of acute bronchitis and asthma attack, we estimated the WTP values from those used by U.S. EPA after conversion[9]. The ratio for conversion was based on the per capita income of U.S. and Shanghai residents. Here the income elasticity was assumed to be 1.

10.3 Results

10.3.1 Unit values for the health endpoints

Table 1 summarized the unit values (mean) for various endpoints associated with air pollution in Shanghai in 2000, and the specific approach used in deriving them.

Table 1. Summary of unit value for various endpoints in 2000 (in 2000 US$)

Endpoint	Mean (95%CI)	Approach
Premature death	108500 (101900,115100)	WTP
Chronic bronchitis	6050 (807,20130)	WTP
Respiratory Hospital admission	710*	COI
Cardiovascular Hospital admission	1043*	COI
Outpatient visits (internal medicine)	14*	COI
Outpatient visits (pediatrics)	14*	COI
Acute bronchitis	7.2 (2.6,11.9)	WTP
Asthma attack	5.3 (2.3,8.3)	WTP

* The available data in Shanghai didn't provide the distribution of the values.

10.3.2 Economic valuation of the health outcomes

Based on "Shanghai Energy Option and Its Health Effects", the health benefits under different energy scenarios with respect to BC scenario in 2010 and 2020 are summarized in tables 2-3, respectively.

Table 2. Health benefits in cases in different scenarios with respect to BC Scenario in Shanghai in 2010 (mean and 95% CI)

0Endpoint	EFF	GAS 2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
Premature death	647 (402, 858)	2937 (1842, 3859)	3275 (2056, 4299)	4538 (2861, 5933)	5472 (3460, 7132)
Chronic bronchitis	1315 (406, 1995)	5964 (1872, 8905)	6649 (2091, 9912)	9210 (2918, 13630)	11100 (3536, 16340)
Respiratory Hospital admission	377 (32, 693)	1740 (146, 3176)	1943 (164, 3545	2712 (229, 4934)	3286 (278, 5967)
Cardiovascular Hospital admission	260 (141, 372)	1197 (654, 1712)	1336 (730, 1911)	1865 (1020, 2663)	2260 (1238, 3224)
Outpatient visits (internal medicine)	27080 (15320, 38620)	125400 (71030, 178800)	140200 (79380, 199800)	196000 (111100, 279300)	237900 (134800, 338900)
Outpatient visits (pediatrics)	2807 (1010, 4571)	13000 (4686, 21150)	14530 (5237, 23620)	20320 (7328, 33020)	24660 (8896, 40050)
Acute bronchitis	49490 (19440, 71710)	223500 (89380, 318100)	249000 (99800, 353900)	344200 (139100, 485100)	414200 (168400, 580400)
Asthma attack	1508 (843, 2076)	6858 (3872, 9354)	7649 (4323, 10420)	10610 (6021, 14390)	12790 (7285, 17300)

Table 3. Health benefits in cases in different scenarios with respect to BC Scenario in Shanghai in 2020 (mean and 95% CI)

Endpoint	EFF	GAS 2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
Premature death	1265 (765, 1726)	6834 (4203, 9161)	6958 (4280, 9325)	9807 (6085, 13030)	11130 (6934, 14730)
Chronic bronchitis	2580 (758, 4115)	13910 (4212, 21520)	14160 (4291, 21900)	19940 (6138, 30370)	22620 (7015, 34230)
Respiratory Hospital admission	704 (58, 1318)	3918 (326, 7244)	3991 (332, 7377)	5707 (477, 10490)	6522 (547, 11960)
Cardiovascular Hospital admission	485 (262, 702)	2694 (1462, 3879)	2744 (1489, 3951)	3924 (2136, 5633)	4485 (2444, 6429)
Outpatient visits (internal medicine)	49850 (28150, 71270)	279600 (158100, 399200)	284900 (161100, 406600)	409200 (231500, 583800)	468600 (265200, 668300)
Outpatient visits (pediatrics)	5173 (1855, 8453)	29000 (10420, 47280)	29540 (10620, 48160)	42430 (15270, 69100)	48590 (17500, 79080)
Acute bronchitis	98520 (36640, 151000)	526400 (202500, 780000)	535900 (206300, 793500)	751300 (294200, 1094000)	850800 (335700, 1230000)
Asthma attack	2937 (1596, 4165)	15910 (8798, 22160)	16200 (8961, 22550)	22860 (12760, 31540)	25960 (14560, 35680)

Combining the health benefits and unit values described above, we compute the economical benefits under different scenarios with respect to BC scenario. Tables 4-5 show the results in 2010 and 2020, respectively.

Table 4. Economic benefits in different scenarios with respect to BAU Scenario in 2010 (millions of 2000 US$) (mean and 95% CI)

	EFF	GAS 2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
Premature death	104.0	469.0	524.0	729.2	873.2
	(72.4, 135.0)	(335.4, 614.2)	(378.2, 677.8)	(513.0, 941.8)	(622.6, 1134.6)
Chronic bronchitis	7.5	34.0	36.9	52.4	60.7
	(1.3, 39.6)	(6.2, 181.6)	(7.0, 203.5)	(10.0, 271.6)	(13.0, 334.2)
Respiratory Hospital	0.4	1.8	2.0	2.9	3.5
admission	(0.1, 0.7)	(0.5, 3.2)	(0.6, 3.5)	(0.8, 4.9)	(1.0, 6.0)
Cardiovascular Hospital	0.4	1.8	2.1	2.9	3.5
admission	(0.3, 0.6)	(1.2, 2.5)	(1.3, 2.8)	(1.8, 3.9)	(2.2, 4.8)
Outpatient visits	0.6	2.6	2.9	4.1	4.9
(internal medicine)	(0.4, 0.8)	(1.7, 3.5)	(1.9, 4.0)	(2.6, 5.5)	(3.2, 6.7)
Outpatient visits	0.1	0.3	0.3	0.4	0.5
(pediatrics)	(0.0, 0.1)	(0.1, 0.4)	(0.1, 0.5)	(0.2, 0.6)	(0.2, 0.8)
Acute bronchitis	0.5	2.2	2.5	3.5	4.1
	(0.2, 1.0)	(0.8, 4.4)	(0.8, 5.0)	(1.2, 6.9)	(1.4, 8.3)
Asthma attack	0.0	0.1	0.1	0.1	0.1
	(0.0, 0.0)	(0.0, 0.1)	(0.0, 0.1)	(0.0, 0.1)	(0.0, 0.2)
Total*	**113.4**	**511.8**	**570.8**	**795.4**	**950.6**

Table 5. Economic benefits in different scenarios with respect to BAU Scenario in 2020 (millions of 2000 US$) (mean and 95% CI)

	EFF	GAS 2	SO2	SO2 + NOx1 target	SO2 + NOx1 target + CO2 tax
Premature death	300.4	1618.4	1647.6	2340.0	2646.0
	(202.6, 399.6)	(1141.2, 2134.0)	(1143.2, 2142.0)	(1632.2, 3044.0)	(1875.4, 3402.0)
Chronic bronchitis	21.6	117.3	118.5	161.8	188.8
	(3.7, 106.2)	(21.2, 633.5)	(21.5, 548.2)	(30.9, 796.2)	(35.4, 985.8)
Respiratory Hospital	1.1	6.1	6.2	8.9	10.2
admission	(0.3, 1.9)	(1.6, 10.6)	(1.6, 10.8)	(2.4, 15.4)	(2.7, 17.6)
Cardiovascular Hospital	1.1	6.2	6.3	9.0	10.3
admission	(0.7, 1.5)	(3.8, 8.5)	(3.9, 8.6)	(5.6, 12.3)	(6.4, 14.1)
Outpatient visits	1.5	8.6	8.7	12.6	14.4
(internal medicine)	(1.0, 2.1)	(5.5, 11.7)	(5.6, 11.9)	(8.0, 17.1)	(9.2, 19.6)
Outpatient visits	0.2	0.9	0.9	1.3	1.5
(pediatrics)	(0.1, 0.2)	(0.4, 1.4)	(0.4, 1.4)	(0.6, 2.0)	(0.7, 2.3)
Acute bronchitis	1.5	7.8	7.8	11.1	12.8
	(0.5, 3.0)	(2.6, 16.2)	(2.7, 16.4)	(3.9, 22.8)	(4.4, 26.2)
Asthma attack	0.0	0.2	0.2	0.3	0.3
	(0.0, 0.1)	(0.1, 0.3)	(0.1, 0.3)	(0.1,0.5)	(0.1,0.5)
Total*	**327.4**	**1765.4**	**1796.1**	**2544.0**	**2884.0**

* Summing 5th and 95th percentile values yield a misleading estimate of the 5th and 95th percentile estimate of total health benefits. As a result, we only present the total mean.

It could be seen that premature deaths dominate the value of the total benefits, accounting for around 90% of the number. In addition, chronic bronchitis also has an important contribution for it.

10.4 Discussion

4.1 Since there had been no original valuation study on the health endpoints associated with air pollution in Shanghai before, we had to estimate values from previous studies of similar changes. This procedure is often termed as *benefit transfer* or *value transfer* in economics. Characteristics of the concerned population, e.g. age distribution, income, health status, culture, may have contextual effects on the valuation results. For example, different social and health insurance systems will greatly influence the risk perception of local population, subsequently resulting in a different WTP to avoid the risk. If we directly transferred the U.S. VOSL into the Shanghai case after considering the income difference between the two sites, a value of US$ 780,000 (in 2000 US$) would be yielded, which is much higher than that estimated according to the Chongqin study. The value would be even higher if we used purchasing power parity (PPP) as the income definition here. It is obvious that the Chongqin result is better fitted to the Shanghai estimation than the US result in terms of economic and social situation. Therefore, the present analysis tries to employ the Chinese studies wherever they are available, and attempts to stay on the conservative side with a range of reasonable estimates.

4.2 The social cost of illness should comprise both the private WTP and the public-borne costs. In the present analysis, the COI approach was employed for valuing certain morbidity endpoints because WTP values were not available. As a result, a mix of either the WTP or the COI approach was used. Actually, the two approaches are not entirely unconnected, and they are interwoven in some way. COI fails to account for the disutility of illness, which is likely to be a major component of willingness to pay for reducing the risk of falling sick; however, some of the cost of illness may not show up in WTP estimates, either. Costs of health care borne by the public sector, for example, will not be reflected in individual willingness to pay. Therefore, in future work, some components of COI estimates may be used to supplement the WTP estimate, to reflect the full cost of illness to society.

A new solution for dealing with the paucity of WTP literature is to integrate the health status index literature with the available WTP literature. The conceptually appropriate WTP values for each morbidity outcome can be obtained given the established correlation between WTP values and health index status. This approach was proposed by TER in 1996[xii]. However, its reliability still needs to be proved in future work.

4.3 A major uncertainty that complicates the application of WTP estimates from the study site to the target site in the benefit transfer arises from difference between income levels. One of the fundamental issues in valuing the reduction of risk is that willingness to pay rises with the income. The key question is the determination of income elasticity of the relevant WTP.

The literature on the income elasticity of WTP for reducing the risk of damage to health is, however, extremely sparse. Different studies estimated the income elasticity from 0.26[xiii] to 1.1[xiv]. It is important to note the acute sensitivity of the social costs of ill health to the value of this parameter. Using an elasticity of 0.4 and 1.1 makes a difference of nearly 20 times in the final results. In view of the limited data source, it is considered prudent to maintain a degree of conservatism in this valuation exercise. Since there is no suggestive information that could be relied on for elasticity estimate, we have chosen to assume a higher income elasticity of 1 for morbidity costs estimates, so that attention is focused on difference in income.

4.4 Double-counting effect still exists since some morbidity endpoints in the present analysis actually are overlapping entities. One example is chronic bronchitis and respiratory hospital admissions, both shown to be related to air pollution and adopted in the present analysis. It is known that respiratory hospital admissions, at least in part, may result from the chronic bronchitis. From this point of view, the present analysis overestimated the economic gains with implementation of various energy scenarios. Based on available data, however, it is difficult to estimate them separately.

10.5 Conclusion

Monetary valuation on the health benefits associated with different energy scenarios has revealed potentially high social benefits from these options. For different scenarios, the economic benefits could reach 113.4-950.6 and 327.4-2884.0 millions U.S. dollars (mean value) in 2010 and 2020, respectively. The results could be used in further cost-benefit analysis of energy options for policy-makers.

10.6 Recommendation for future research

The uncertainties in the above estimation process highlight the need for a variety of new and continued research efforts. Based on the finding of this study, the highest priority research needs are recommended as following:

- As there exists inherent uncertainty during the process of value transfer from the study sites (e.g. Chongqin, USA) to Shanghai, an original WTP study for the avoidance of air pollution-related health risks in Shanghai is encouraged, especially on the WTP to reduce the risk of deaths brought forward by air pollution. Additional research is needed to enhance our ability to value the health outcomes associated with air pollution, which should include the different factors (e.g. age, income, education, pollution level) influencing WTP; the relationship between WTP and quality of life; investigation of private costs and lost output; people's preference in trading off future risks etc.

- Due to the paucity of WTP literatures on some morbidity endpoints, even in the international database., alternative methods should be developed in this field, which include: the relationship between known health status index and WTP for the avoidance of some morbidity endpoints, application of aggregate measures such as DALYs that don't involve direct costing of the health outcomes, etc.

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